Two further threats to Ireland's trees from non-native invasive Phytophthoras

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Abstract

The genus *Phytophthora* contains many plant pathogens, including the causal agents of sudden larch death (*Phytophthora ramorum*) and of the late potato blight (*P. infestans*). *Phytophthora* species are estimated to be one of the most threatening biotic agents to forest health worldwide. The species *P. austrocedri* and *P. pinifolia* are currently causing disease epidemics in forests in Argentina and Chile, respectively. Although neither species has yet been recorded in Ireland, *P. austrocedri* has recently been found in Britain. The threat that *P. austrocedri* and *P. pinifolia* pose to Irish forests is briefly reviewed in this paper. The threat level posed by these species is ranked in relation to the risk of (i) entry into Ireland and (ii) likely establishment of species in the wild in Ireland. *P. austrocedri* is of medium threat to Irish forests, given that it is currently present in Britain and has been found in 2001 in Germany on an imported ornamental juniper plant. Furthermore, known hosts of *P. austrocedri* are distributed across the Irish landscape. *P. pinifolia* was ranked as being a low level threat to Ireland's forests. This ranking is a result of the lack of any obvious entry pathway for the pathogen into Ireland and the low frequency of suitable hosts for the organism in Ireland. A large degree of uncertainty in the biology of these organisms was evident from this analysis. Once a pathogen becomes established in the wild, it can be very difficult to eradicate. Being situated at the edge of Europe, Ireland is in a good position to monitor current forest epidemics in mainland European forests and to act to prevent similar outbreaks in Irish forests.

Keywords: *Forest pathogen, invasive species, pest risk analysis, South America, juniper, pine.*

Introduction

Phytophthora species are a significant threat to forest health worldwide (Balci and Bienapfl 2013, Jung et al. 2013a). More than half of the currently described 120 species are found in forests and many of these are pathogenic on trees and woody shrubs (Scott et al. 2013). In Ireland and Britain several *Phytophthora* species have been found causing damage to trees and shrubs in natural environments. These include *Phytophthora alni* (Brasier and Kirk), *P. kernoviae* (Brasier, Beales and Kirk), *P. lateralis* (Tucker and Milbrath), *P. ramorum* (Werres, De Cock and Man in't Veld) and *P. pseudosyringae* (Jung and Delatour) (Brennan et al. 2010, Jung et al. 2013a, McCracken 2013, Denton 2014). All of these species are non-native and were most likely introduced on living plants. In South America, two of the most serious forest

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pathogen epidemics at present are Mal del ciprés (cypress sickness) in Argentina and Daño foliar del Pino (pine foliar damage) in Chile (Frankel and Hansen 2011), caused by *P. austrocedri*[1] (Gresl. and E.M. Hansen) and *P. pinifolia* (Alv. Durán, Gryzenh. and M.J. Wingf.), respectively. Both of these *Phytophthora* species are assumed to be non-native to these countries and were likely introduced by humans. Neither of these species has yet been recorded in Ireland, but *P. austrocedri* has recently been found in Britain (Green et al. 2014). These two species can be added to the list provided by McCracken (2013) that identified pathogens and pests with a reasonable chance of threatening the health of Irish trees.

The aims of this article are to review the current literature on both of these pathogens and assess the level of threat they pose to Irish trees and forests, taking into account the likelihood of entry and establishment of the organisms in Ireland. The official process of rating the phytosanitary threat that a non-native organism poses to the plant health of a country is known as Pest Risk Analysis (PRA). While this article is not an attempt to carry out a PRA for *P. austrocedri* or *P. pinifolia*, these pathogens were assessed under one of the main sections of the PRA process, namely "probability of introduction and spread" (ISPM 2) from an Irish context. A further aim of this article is to bring these emerging forest pathogens to the attention of Irish foresters, similar to the warning given by Keane (1986) of the future threat (now realised!) of *P. lateralis* to Lawson cypress (*Chamaecyparis lawsoniana* (A. Murray) in Ireland.

The emergence of P. austrocedri *in Argentina and Britain*

The disease symptoms of Mal del ciprés were first noted as far back as 1950 in trees within the Isla Victoria forest experiment in the Patagonian region of Argentina (Greslebin et al. 2005). As often happens with *Phytophthora* epidemics on trees, the forest decline was first attributed to several other factors (both biotic and abiotic) before the causal agent was identified. Finally, in 2007 collaborative work between Oregon State University and Argentinian researchers led to the discovery and naming of the causal agent, *P. austrocedri* (Greslebin et al. 2007, Greslebin and Hansen 2010). The disease now extends at least 400 km south from the Neuquen province through the Rio Negro and Chubut provinces of Argentina (Velez et al. 2014). The current disease epidemic is thought to affect only the endemic tree species, Chilean cedar (*Austrocedrus chilensis* D. Don) in the forests of the Patagonian region (Greslebin et al. 2007) and causes high mortality leading to predicted changes in the future composition of these forests (Amoroso et al. 2012). Recently however, a pest alert

[1] Although the use of the synonym *Phytophthora austrocedrae* has been frequent in the literature and online, at the 7th Meeting of the International Union of Forest Research Organisations Working Party (IUFRO) 7.02.09, entitled Phytophthoras in Forests and Natural Ecosystems, a decision was made to adhere to the original and correct version of the species name, *Phytophthora austrocedri*.

identifying the threat of *Phytophthora austrocedri* to the heathland species common juniper (*Juniperus communis* L.) and also to Lawson cypress and Alaska yellow cedar (*Cupressus nootkatensis* D. Don) was circulated by the Forestry Commission (2014a). In Britain, symptoms of disease were noted on native common juniper at several sites in northern England and Scotland in the mid 2000's (Green et al. 2014). The relatively rapid dieback of juniper has since been noted in many areas in Scotland and England, with *P. austrocedri* being identified as the causal agent. *P. austrocedri* is now known to be widely distributed on common juniper across northern Britain, with two distribution clusters of the pathogen; in the lake district of Cumbria and in the northeast highlands of Scotland where common juniper is most common. To date, *P. austrocedri* has not been reported in any natural stands south of Yorkshire. The organism has also been found in private gardens in England and Wales (Forestry Commission 2014b). All of the findings in Britain, except two on individual Lawson cypress and Alaska yellow cedar trees, have been on juniper. All of the known hosts of *P. austrocedri* so far have been from the Cupressaceae, possibly indicating that the organism has an affinity to this plant family (Green et al. 2014). Although it is not clear whether the pathogen is native or introduced to either Britain (Green et al. 2014) or Argentina (LaManna et al. 2012, Velez et al. 2014), the genetic evidence seems to point to it being an introduced species in both regions.

Studies using *P. austrocedri* isolates from Argentina have found that the species has non-deciduous sporangia (i.e. infective spores that do not fall off easily) and infection by *P. austrocedri* occurs via the root as the motile zoospores (i.e. swimming spores released from sporangia) swim through water in the soil to infect the roots. Progression of the infection up the inner bark and sapwood follows, causing necrosis of the phloem and xylem which leads to disrupted carbohydrate and water transport, resulting in the plant being girdled (Velez et al. 2012). Early symptoms include thinning of the crown foliage (Figure 1) and bleeding lesions on the lower stem. As with other soil borne pathogens, tree death at the landscape scale can radiate out from central infection foci (Figure 2). Studies in Britain are underway to describe the ecology of the organism and the infection process on juniper (Sarah Green personal communication). *P. austrocedri* is spread at a local level in watercourses and by animal and humans moving soil in Argentina (La Manna et al. 2012, Hansen 2015). A similar local mode of spread is being postulated by researchers in Britain, with scientists investigating the role of animals in spreading the disease (Sarah Green, pers. comm.). Furthermore, phytosanitary precautions, such as washing debris from footwear, are being encouraged for people that visit affected areas. The role of plant nurseries in spreading the organism over long distances through international trading of infected juniper plants has also been suggested (Forestry Commission 2014a, Werres et al. 2014).

Figure 1: *Declining and healthy* Austrocedrus chilensis *trees in Isla Victoria, Argentina. Tree decline can be seen as a thinning of foliage in the trees to the left centre and centre of the picture. The tree on the right centre of the picture appears to be unaffected.*

Figure 2: *Tree death as a result of Mal del cipres in Patagonia, Argentina. The light green trees are healthy* Austrocedrus chilensis, *the dark green trees are* Nothofagus *spp., the grey areas are dead* A. chilensis *trees***.**

Occurrence of *Phytophthora pinifolia* in Chile

Forest damage caused by *P. pinifolia* was first recorded in Monterey pine (*Pinus radiata* D. Don) forests in coastal Chile in 2004 (Ahumada et al. 2013a). It is generally accepted to be the most serious threat to pine forestry in Chile because of its rapid spread and its ability to damage pine trees of all ages. The organism mainly affects the foliage and non-fatal infections are the norm with many areas of previously infected forest showing recovery. The area of pine forests affected by this disease has fluctuated from year to year, increasing from an initial 70 ha in 2004 to the maximum recorded 60,000 ha in 2006. From 2007 onwards the area affected varied considerably, with the area affected in 2011 totalling 2,000 ha (Ahumada et al. 2013a). In recent years the epidemic seems to have collapsed, with symptoms only being seen on scattered pine trees (Hansen 2015). Given the absence of any disease symptoms prior to 2004 and the low genetic variation in the disease population in Chile, it is believed that the pathogen is an introduced species (Durán et al. 2010), probably becoming established in Chile in the years just prior to 2004.

Infection by *P. pinifolia* typically occurs during the wet seasons (winter and spring in Chile), with the pathogen infecting the needles and succulent tissue of the tree via sporangial spread in rain splash and rain mists (Ahumada et al. 2013a). Infection often causes black bands on the needles, with the infected needles dying relatively quickly. These black bands on the needles are the sites of sporangia production (Durán et al. 2008). The foliage at the top of infected trees turns grey, with the foliage of the entire tree turning brown at the end of spring (Ahumada et al. 2013a). The pathogen rarely enters the bark or wood of the host and would appear to persist mainly in the needles (Ahumada et al. 2012). The next season's needle growth is not affected, unless reinfection from litter or near-by infected trees occurs. However, several consecutive years of infection can lead to high stress on the trees, making them susceptible to secondary infections from other pathogens/facultative pathogens which can cause tree death. The incidence of death declines as tree get older, with the pathogen typically killing 1-2 year-old saplings, yet rarely killing trees older than 6 years-old.

Suitability of climate and host range for P. austrocedri *and* P. pinifolia

The cool temperate maritime climate of Ireland provides conditions favourable for the establishment and survival of many *Phytophthora* species, most of which have a wide threshold of growth temperatures, ranging from 1 °C to 35 °C (Erwin and Riberio 2005). Being a semi-aquatic organism, *Phytophthora* also favours moist conditions and the presence of free water is necessary for natural infection via zoospores (Erwin and Riberio 2005). Future climate change predictions for Ireland indicate that temperatures will likely rise c. 1.5 °C while rainfall during the autumn/winter will also increase as this century progresses (Mc Grath et al. 2005). These changes will increase the suitability of

the Irish climate for *Phytophthora* establishment, directly by allowing better conditions for infection and growth into the plant and indirectly by stressing the plant with knock-on negative effects on plant defences (Pautasso et al. 2012).

The threat assessment for *P. austrocedri* carried out by British scientists indicated, at that time, that the natural environment of Britain was suitable for establishment of the organism (Webber et al. 2012). Studies using two Argentinian isolates of *P. austrocedri* revealed that the organism can grow at temperatures ranging from 10 to 25 °C, with an optimum of 17.5 °C (Greslebin et al. 2007). Further work carried out on a wider range of isolates (from Britain and Argentina) has found that 25 °C is the maximum temperature for growth (Sarah Green pers. comm.). This range of temperatures is within the normal range for Ireland and Britain. The range of temperatures for growth of *P. pinifolia* is from 10 to 30 °C, with optimum growth achieved at 25 °C (Durán et al. 2008). This range also occurs within Ireland's temperature range. The climatic range for *P. pinifolia* is said to be very similar, although slightly cooler, than that of *P. ramorum* in North America (EPPO 2010). Given that the climate of Ireland and Britain are suited to *P. ramorum* establishment, it could be expected that *P. pinifolia* would also survive under Irish climatic conditions. Indeed, a climate modelling task commissioned by EPPO (2010) identified the south west of Ireland to be climatically suitable for the establishment of *P. pinifoli*. The Atlantic coast region of Ireland may also be more conducive to the spread of the pathogens if they did invade. The rainfall in the west and in mountainous areas ranges from 1,000 mm to more than 2,000 mm in some areas (MET Eireann 2015). Free water is necessary for infection by many *Phytophthora* species and the infection levels and spread of *P. austrocedri* and *P. pinifolia* would also increase under these conditions.

At present, neither *P. austrocedri* nor *P. pinifolia* have been reported in Ireland. *P. austrocedri* has been recorded in Britain and the finding of a specific plant pathogen in Britain is often indicative that the same pathogen may soon be recorded in Ireland (Table 1). This is partly because both countries trade in the same European market, in similar commodities from those markets and have a similar range of habitats (both artificial and natural). When taking the ecology of the two pathogens into account, the Irish climate appears suitable for their establishment in the wild. Given that *P. austrocedri* can survive in the wild in Britain, probably indicates that it would also be able to survive in Irish conditions. Furthermore, given that similar habitat to that infected by *P. austrocedri* also exists in Ireland, the likelihood of establishment in Irish juniper ecosystems should be taken as high. The temperature in Ireland is often below the minimum temperature for growth of *P. pinifolia* (10 °C), however, other species with similar minimum growth temperatures (e.g. *P. cinnamomi*, *P. richardiae*) have been found infrequently in the wild in Ireland in the past (Muskett and Malone 1974). This indicates that the Irish climate, which is considered unfavourable for the

disease, cannot be taken as a guarantee that a species will not survive in the wild. In periods of unfavourable conditions, many *Phytophthora* species form resistant "resting" structures. *P. pinifolia* does not produce any known resistant structures, but *P. austrocedri* can produce them in the form of oospores (Greslebin et al. 2007). These structures would enable the species to survive at conditions outside of its normal growth range, for example at low temperatures or under low water availability, as has been shown for *P. cinnamomi* in Australia (Jung et al. 2013b).

The host range of both *P. austrocedri* and *P. pinifolia* has so far been shown to be rather narrow - with just four (*A. chilensis*, *J. communis*, *C. lawsoniana*, *C. nootkatensis*) and one (*Pinus radiata*) known hosts in the wild, respectively. Common juniper has the largest worldwide natural distribution of any woody plant, extending across the northern hemisphere from Asia through Europe and North America (Eckenwalder 2009). In Ireland, common juniper occurs in montane and heath ecosystems, especially along the north and west coast (Cooper et al. 2012). Of the known tree hosts to occur in Ireland, both *C. lawsoniana* and *C. nootkatensis* have a rather restricted distribution, especially the latter. *C. lawsoniana* is commonly used as an amenity species and infrequently (<360 ha; NFI 2012) as a forestry species. If *P. austrocedri* is indeed restricted to hosts within the plant family Cupressaceae, then the species coast redwood (*Sequoia sempervirens* (D. Don) Endl.) and western red cedar (*Thuja plicata* Donn ex D. Don) which make up 70 ha of Irish forests could also be susceptible.

Of similar restricted distribution in Irish forestry is Monterey or radiata pine (*Pinus radiata*), the only known host for *P. pinifolia* in the wild, which only accounts for 240 ha of Irish forests. Planting guidance for the use of *P. radiata* recommends planting in warm regions, such as the south and south west of Ireland (Horgan et al. 2004). This also happens to be the area of Ireland most suitable for epidemics of other forest *Phytophthora* species, *P. ramorum* and *P. kernoviae* (DAFM 2014a), which might indicate suitability of the climate in this region for *P. pinifolia* also.

Table 1: *First record of selected plant pathogens in Britain and Ireland. Data from EPPO reporting service (http://archives.eppo.int/EPPOReporting/Reporting_Archives.htm).*

Outbreak	Britain	Ireland
Phytophthora ramorum in horticulture	2002	2002
P. ramorum in Rhododendron outdoors	2003	2004
P. ramorum in Japanese larch outdoors	2009	2010
P. kernoviae in Rhododendron outdoors	2003	2008
P. lateralis in Lawson cypress outdoors	2010	2011
Hymenoscyphus fraxineus (syn. *Chalara fraxinea*) in horticulture	2012	2012
H. fraxineus (syn. *C. fraxinea*) in ash outdoors	2012	2013

In Irish forestry, four pine species (*Pinus contorta* (Doug.), *P. sylvestris* (L.), *P. nigra* (J.F.Arnold), *P. radiata*) make up about 70,000 ha of the forest estate (NFI 2012). Only *P. radiata* was tested for susceptibility to *Phytophthora pinifolia* in the laboratory tests of Ahumada et al. (2013b) and these tests indicate that *Pinus radiata* was one of the most susceptible. There was a large variability in susceptibility between the nine *Pinus* species tested. This variability in susceptibility was further reflected in the evidence from field observations, which showed that other conifers, including *P. pinaster* (Ait.), remained uninfected despite being in the vicinity of infected *P. radiata* trees. This field monitoring evidence also indicates that *Phytophthora pinifolia* is restricted to hosts of the genus *Pinus* in the wild.

Introduction pathways for P. austrocedri *and* P. pinifolia *into Ireland*

In phytosanitary terms, a pathway is a route by which a pathogen or pest can move from one region to another. The two main pathways known to be important in spreading plant pests and pathogens internationally are the "wood packaging material" (ISPM 15; see also Humble 2010) and the "plants-for-planting" (ISPM 36, see also EPPO 2012) pathways. Plants-for-planting are officially defined as "Plants intended to remain planted, to be planted or replanted" (ISPM 5). The plants-for-planting pathway has been highlighted as a major contributor to the worldwide spread of plant pathogens (Webber 2010), including the internationally important pathogens *P. cinnamomi* Rands (cinnamomi root rot), *Cronartium ribicola* J.C. Fisch. (white pine blister rust), *Mycosphaerella pini* Rostr. ex Munk (Dothistroma needle blight) and *P. ramorum* (sudden oak death, sudden larch death). Trade in juniper plants has been implicated in the introduction and spread of *P. austrocedri* in Britain (Green et al. 2014). Indeed, analysis of archived *Phytophthora* specimens isolated from imported plants in Germany in 2001 indicated that the pathogen was found previously on a *Juniperus horizontalis* Moench sample (Werres et al. 2014). The phytosanitary threat assessment for *P. austrocedri* also highlighted the role of the plants-for-planting route in disease spread and warnings were given about the lack of any specific phytosanitary requirements for *P. austrocedri* in the EC Plant Health Directive, making further introductions of the pathogen from Europe into Britain likely (Webber et al. 2012). From 2010 to 2014, the value of imports of live outdoor plants into Ireland totalled €1.5 million (EUROSTAT 2015) and this category includes to a small extent juniper planting stock. Regarding *P. pinifolia*, the main pathway of introduction is also through plants-for-planting, most likely of *Pinus* species. Importing of *Pinus* trees, as well as other conifers such as *Abies*, *Pseudotsuga* and *Juniperus* spp. is prohibited into the EU from a third country under the EU Plant Health Directive (2000/29/EC). Given the already existing dangers these plants could pose because of the occurrence of other *Pinus* pests (e.g. pine wilt nematode) and diseases (e.g. *Dothistroma* needle

blight, pine pitch canker) in other regions, it is unlikely that *P. pinifolia* will enter Ireland via this pathway. Ireland has in the past imported living forest trees from EU countries; however, there have been no recorded imports of this commodity since 2009 according to available data (EUROSTAT 2015).

Are P. austrocedri *and* P. pinifolia *imminent threats to Ireland's trees?*

By reviewing the available literature on both *P. austrocedri* and *P. pinifolia* and taking into account the climate and suitable host distribution in Ireland, it is possible to rate in a similar system to that of McCracken (2013), the level of danger that these organisms will pose to the health of trees and forests in Ireland (Table 2). Given the likely pathway for entry and the widespread distribution of possible hosts for *P. austrocedri*, this species should be rated as of medium concern to Ireland's trees, similar to the ratings for *P. kernoviae* and *Pseudomonas syringae pv. aesculi* (horse chestnut bleeding canker) (McCracken 2013). While the risk of entry is high, the number and distribution of tree hosts at risk from the organism is only moderate, thus lowering the threat level of this organism. Outside of Irish forests, the risk to Irish ecosystems containing common juniper from *P. austrocedri* is very high. Juniper distribution in Ireland is declining due to a number of factors, including encroachment and livestock grazing (Cooper et al. 2012). In Britain the spread of *P. austrocedri* has been attributed to several possible causes, including where juniper habitats were re-established with nursery-grown juniper plants, the high number of visitors to juniper sites by nature conservancy groups (e.g. Royal Society for the Protection of Birds; RSPB) and grazing by livestock on juniper sites. Given that nursery-grown plants were used in Britain for juniper re-establishment and that nursery-grown plants have been found to be infected with *P. austrocedri*, it is possible that such re-establishment works inadvertently spread the disease. In Ireland, care must be taken not to introduce and spread *P. austrocedri* into Irish juniper habitats.

Phytophthora pinifolia on the other hand, is unlikely to enter the country and

Table 2: *Diseases caused by* Phytophthora austrocedri *and* P. pinifolia *of concern to Irish trees and forests.*

Causal agent	*Phytophthora austrocedri*	*Phytophthora pinifolia*
Disease name	Mal del ciprés	Daño foliar del Pino
Main host of concern	Common juniper and other members of the family Cupressaceae	Monterey pine and other *Pinus* species
EPPO status	No EPPO status; Rapid Risk Assessment (Webber et al. 2012)	Alert list 2009-2013; Rapid PRA planned
First report in Ireland	Not reported	Not reported
Level of concern	Medium	Low

if it did enter it is unlikely to find a suitable host. For these reasons it should be rated as an organism of low threat to Irish forestry (Table 2), similar to *P. lateralis* and horse chestnut leaf miner *(Cameraria ohridella)* (McCracken 2013). Probably of more threat to the pine forests of Ireland are the fungal pathogens *Mycosphaerella pini* (causal agent of *Dothistroma* needle blight) and *Gibberella circinata* (Nirenberg and O'Donnell) (causal agent of pitch pine canker) should they ever enter the country.

It must be remembered though, that this analysis is rudimentary in many ways and thus underestimates the actual threat level of these pathogens. As with other analyses of the phytosanitary threat of pathogens and pest (e.g. PRA), uncertainty is an issue (Burgman et al. 2014). There are currently many areas of uncertainty regarding the threat posed by these two *Phytophthora* species, such as lack of information about the biology of the pathogens, their host range and the introduction pathways they could use. Future research into where these pathogens come from, how they interact with their host and the environment and possible ways to prevent/mitigate their respective epidemics, may remove many of these uncertainties.

Conclusions

The threat level to Irish trees from the pathogens *P. austrocedri* and *P. pinifolia* were rated as medium and low, respectively. Other pathogens absent from Ireland yet present in Britain, Europe or world-wide probably pose more of a threat to Irish forestry. In particular, pathogens and pests that threaten the health of Ireland's spruce forests, especially Sitka spruce, are more worrying and need to be identified via horizon scanning exercises. Forest pathologists have realised that the best and often only effective strategy for forest pathogen management is exclusion (Roy et al. 2014, Hansen 2015). With this in mind, research focus has moved from a reactive to a more proactive emphasis. Horizon scanning (Eschen et al. 2014), spread modelling (Pautasso 2013), trait analysis (Philibert et al. 2011) and sentinel planting (Vettraino et al. 2015) research are some of the ways in which forest pathologists and entomologists are forecasting what could be the next Dutch elm disease or ash dieback epidemic. The switch to a more proactive focus is also occurring at policy level in Ireland, with the recent forest policy report containing a strategic action to monitor emerging pests and pathogens of forest trees abroad to prevent introduction into Ireland (DAFM 2014b). Ireland is often one of the last countries to get a forest pathogen or pest that is spreading through Europe (e.g. ash dieback) and this is partly due to being an island on the edge of Europe. This position offers us the advantage of anticipating and being prepared for the most likely threats by monitoring pathogen and pest developments (and movements) in Europe. Hopefully this will allow us to make timely changes that prevent or mitigate against future epidemics in our forests.

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