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Forest Phytophthora diseases in the Americas: 2007 – 2010†

Susan J. Frankel[1,*] and Everett M. Hansen[2]

[1]USDA Forest Service, Pacific Southwest Research Station, 800 Buchanan Street, Albany, CA, 94710, USA.
[2] Department of Botany and Plant Pathology, Cordley Hall, Oregon State University, Corvallis, OR, 97331, USA.

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*corresponding author: sfrankel@fs.fed.us

Abstract

Recent findings, policy, regulation, and management relating to tree disease caused by *Phytophthora* species in wildlands and nurseries of North and South America are reviewed. These include the isolation of *Phytophthora alni uniformis* Brasier & S.A.Kirk in Alaska, and detection of population shifts in NA1, NA2 and EU1 clonal lineages of *Phytophthora ramorum* Werres, de Cock, & In't Veld. The dissemination of *Phytophthora ramorum* from infested nurseries in water run-off presents a challenge for forest and plantation management. In the United States, forest Phytophthoras are viewed as a biosecurity threat and are monitored by the United States Department of Agriculture, Animal and Plant Health Inspection Service but tools designed to protect forests and nurseries need refinement. In Mexico, *Phytophthora cinnamomi* Rand is recognised as a threat to *Quercus* forests. The *Phytophthora pinifolia* Alv. Durán, Gryzenh. & M.J.Wingf. epidemic in Chilean *Pinus radiata* D.Don plantations has receded. Work with *Phytophthora austrocedrae* Gresl. & E.M.Hansen continues in Argentina.

Keywords: forest pathogens; forest *Phytophthora* species; invasive species; *Phytophthora ramorum.*

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Introduction

Because *Phytophthora* species do not cause unique symptoms, and because they require specific isolation techniques, they often remain unrecognised. Many parts of North, Central and South America have not been surveyed by forest pathologists or other interested parties. Forest Phytophthoras in the Americas were last reviewed by Rizzo and Fichtner (2009).This paper covers recent findings and current issues concerning the pathological activity of Phytophthoras in North and South American forests.

Four new forest *Phytophthora* species were described from the Americas between 2007 and March 2010. These were: *Phytophthora pinifolia* Alv. Durán, Gryzenh. & M.J.Wingf., *Phytophthora sansomeana* E.M.Hansen, *P. siskiyouensis* Reeser & E.M.Hansen and *Phytophthora quercetorum* Balci & Balci (Table 1).

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North America

Phytophthora alni uniformis (PAU) in Alaska

Phytophthora alni uniformis Brasier & S.A.Kirk was detected in 2007 – 2008 during riparian surveys in Alaska (Adams et al., 2008; Adams et al., 2010). It is thought to have hybridised with *P. alni* subsp. *multiformis* Brasier & S.A.Kirk to form the highly pathogenic *P. alni* subsp. *alni* Brasier & S.A.Kirk known to kill alder, *Alnus* spp., in Europe (Ioos et al., 2006). This was the first finding of a *P. alni* subspecies in North America.

The PAU discovery in Alaska was made during a survey of dieback and mortality in thinleaf alder, *Alnus incana* (L.) Moench ssp. *tenuifolia* (Nutt.) Breitung. The dieback symptoms have been attributed to cytospora canker development associated with heat stress (Ruess et al., 2009; Worrall, 2009; Worrall et al., 2010) and PAU is not regarded as an alder pathogen in Alaska.

The first isolations of Alaskan PAU were made from soil around alder roots on the Kenai Peninsula and near Denali National Park. These two remote, unmanaged areas are hundreds of km apart. In 2008, an expanded survey of riparian soils associated with alders yielded several *Phytophthora* species that had not been reported previously in the United States of America. These included *Phytophthora gallica* T.Jung & J.Nechwatal; an undescribed species in internal transcribed spacer (ITS) Clade 8C that was closely related to *Phytophthora ramorum* Werres, de Cock,& In't Veld; and *Phytophthora foliorum* Donahoo & Lamour, as well as other, undescribed species. Approximately 600 *Phytophthora* isolates recovered by soil baiting were sequenced and 33 different genotypes of PAU were identified. These had been collected from 11 alder stands. Only one isolate was obtained from bait floating in the Tanana River, of 81 watercourses sampled. According to Adams (2010), PAU is widely-distributed and difficult to isolate.

In a subsequent investigation, results from streamwater baiting were compared with those from soil sampling (Reeser, Sutton, Hansen, Remigi, & Adams, 2011; Reeser, Sutton, & Hansen, 2011). *Phytophthora* spp. were present in 28 of the 49 Alaskan streams, i.e. 57% of sites baited in the single 2-week-sampling period investigated. These were located between the Kenai Peninsula in the south and in an area north of Fairbanks in the interior. *Phytophthora gonapodyides* (H.E.Petersen) Buisman and other Clade 6 species were most abundant (267/274 isolates, 97%). Seven species were identified, including two in ITS Clade 6 that had not been described previously. Both of these were found in several streams in the southern and northern sampling areas. Species in clades other than Clade 6 were infrequent. They included *Phytophthora cactorum* (Lebert & Cohn) J. Schr and *Phytophthora pseudosyringae* T. Jung & Delatour.

Phytophthora siskiyouensis on alder in Southern California

The initial Southern California reports of *Phytophthora siskiyouensis* (Coffey & Matthews, 2009; Palmieri et al., 2009) resulted from an investigation of the cause of decline in white alder (*Alnus rhombifolia* Nutt.). Affected trees were found in commercial and residential areas in Orange County. Symptoms included upper canopy dieback, tree mortality, and dark brown bleeding spots on stem bark. In 2007, similar symptoms and dieback caused by *P. siskiyouensis* were reported on planted Italian alder (*Alnus cordata* (Loisel.) Duby) in Foster City, San Mateo County (Rooney-Latham et al., 2007; 2009). In these cases, the pathogen appears to be introduced to these environments via planting of infected nursery-grown landscape plants. First reports of *P. siskiyouensis* on tanoak, *Notholithocarpus densiflorus* (Hook & Arn.) Rehder Manos, Cannon, & Oh and on myrtlewood, *Umbellularia californica* (Hook. & Arn.) Nutt., as well as in soil and water had come from southwest Oregon (Reeser et al., 2007).

Phytophthora lateralis Tucker & Milbrath

Protection and restoration measures for Port Orford cedar, *Chamaecyparis lawsoniana* (A.Murray) Parl., threatened by *P. lateralis* Tucker & Milbrath in southwest Oregon and northern California, are mandated in forest plans and other management documents relating to Federal land. Mitigation procedures including permanent or seasonal road closures and harvesting restrictions, vehicle washing, and roadside sanitation are incorporated in forest plans and operations.

TABLE 1: *Phytophthora* species detected in forests or forest nurseries in the Americas since the 2007 IUFRO meeting.

Phytophthora species	Habitat	Location	Reference
P. pinifolia	Radiata pine foliage	Chile	Durán et al., 2008
P. sansomeana	Douglas-fir nursery	North-western USA	Hansen et al., 2009
P. siskiyouensis	Tanoak forest	North-western USA	Reeser et al., 2007
P. quercetorum	Oak forest soil	Eastern USA	Balci et al., 2008

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In a cooperative screening programme run by Oregon State University, the Forest Service and the Bureau of Land Management to identify resistant Port Orford -cedar individuals, more than 12 500 Port Orford cedar trees have been tested for resistance to *P. lateralis.* Approximately 700 of these showed resistance in the first round of stem dip testing. Trees with higher levels of resistance are used for propagation in a containerised seed orchard. Seedlings are subjected to further testing, and orchard seed is available to forest tree nurseries.

The largest planting to date of resistant Port Orford cedar took place in 2010 when 86 000 seedlings were established on 260 ha following wildfires in the Six Rivers National Forest in Del Norte County, California (Frank Betlejewski personal communication, March 9, 2010). *Phytophthora lateralis*-resistant Port Orford cedar became commercially available in the United States when the Monrovia Nursery released the "Guardian Series™", (Monrovia, 2008). This consisted of four varieties grafted to resistant root stock developed by the Hansen Laboratory at Oregon State University as part of their cooperative resistance program with the United States Department of Agriculture (USDA) Forest Service.

Reports of new outbreaks of *Phytophthora lateralis* in France (C. Robin, this meeting and 2010), and discovery of *P. lateralis* in Taiwan (Brasier et al., 2010) ensure that more will be heard about this pathogen.

Phytophthora ramorum

This species continues to be the most intensively managed, monitored and researched forest *Phytophthora* species in North America. A complete bibliography is maintained by the California Oak Mortality Task Force (www.suddenoakdeath.org). Additional reports describing the control programme in southwest Oregon are included in the Proceedings of this conference so only brief summaries of select, significant new findings for the 3 recognised lineages, NA1, NA2 and EU1 (Grünwald et al., 2009) are presented here.

First detection of* Phytophthora ramorum *in a Californian bishop pine forest

In spring 2009, *Phytophthora ramorum* was found on tanoak trees located in a bishop pine (*Pinus muricata* D.Don) stand in MacKerricher State Park, 5 km north of Fort Bragg in Mendocino County, California. This site was approximately 66 km south of the nearest previously known location of the pathogen (Humboldt County). This outbreak was of particular concern because native bishop pine are only found in limited, disjunct populations along the California coast, adapted to unique soils (Millar, 1986). In a collaborative effort to prevent spread of the pathogen, officials from the California State Parks and the California Department of Forestry and Fire Protection removed infected tanoaks from the Park campground (Palmieri et al., 2009).

First official (regulatory) record of* Phytophthora ramorum *transfer from nursery to forest; first US non-nursery detection of the NA2 clonal lineage

The first instance of *Phytophthora ramorum* as the cause of disease in forest vegetation adjacent to an infected nursery was recorded in 2009 in Pierce County, Washington (California Oak Mortality Task Force (COMTF), 2009a). Infected salal (*Gaultheria shallon* Pursh) plants were discovered on County land around a roadside creek during a survey of the perimeter of a retail nursery. Two *P. ramorum*-positive *Rhododendron* L. cultivars were detected in the nursery in May and June 2009. Water draining into the salal area was found to carry *P. ramorum* and was suspected to be the pathway for the new infection. *Phytophthora ramorum* had also been identified in two cultivars of *Camellia* L. in 2003, and in 14 cultivars of *Camellia* and *Rhododendron* in 2004 (California Oak Mortality Task Force (COMTF), 2009a). The salal infection was the first non-nursery detection of the NA2 *P. ramorum* strain[1] previously found only on nursery stock in California, Oregon and Washington (Elliot et al., 2009).

Federal, State and County agriculture and forestry officials are collaborating on the response; salal showing signs of infection was killed using herbicides in an effort to prevent pathogen spread. Soil, vegetation, and water in the immediate area are being monitored for presence of the pathogen (COMTF, 2009b).

Detection of* Phytophthora ramorum *in streamwater near infected nurseries; other occurrences near nurseries

Phytophthora ramorum has been detected in drainage ditches, streams and other waterways near infected nurseries at 10 locations in seven states (Chastagner et al., 2010). In 2009, it was found in streams outside nurseries in five states: Washington (1); Mississippi (1); Alabama (2); Georgia (1); and Florida (1). Multiple detections were noted in each case. Six records of

[1] *Chastagner, G., Coats, K., & Elliott, M. (2009). [Unpublished report].* Understanding the mechanism(s) behind repeat detections of *Phytophthora ramorum* in Washington nurseries and streams using DNA fingerprinting technology. *Progress Report on Funded Nursery Projects Washington State Department of Agriculture, December 30, 2009.*

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TABLE 2: Incidence of *Phyophthora ramorum* in US nurseries and associated landscape detections (United States Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS), 2010a).

Year	Nurseries	States	Comments
2000	0		There were no reported nursery detections prior to 2001
2001	1	1 (CA)	
2002	0		
2003	20	3 (CA, OR, WA)	
2004	176	21	125 linked to one nursery's shipments
2005	99	7	
2006	62	11	
2007	23	6	
2008	28	8	
2009	26	11	Also, 6 landscape detections in 4 states
2010	34	10	Includes 1 greenhouse, also 2 landscape detections

P. ramorum on species recently used for amenity planting have been documented: three in Washington and one each in Maryland, Pennsylvania, and South Carolina (Palmieri et al., 2009).

The number of detections of *Phytophthora ramorum* in US nurseries averaged 26 in the period 2007 – 2009 (Table 2). Between 2007 and 2010, 24 plant species (Table 3) were added to the official list as associated hosts (USDA APHIS, 2010b). These are now subject to interstate regulation of shipping of nursery stock.

Phytophthora ramorum *migration patterns; frequency of detection of clonal lineages NA1, EU1 and NA2*

Genetic analysis of Washington State, Oregon, California, other US and Canadian isolate collections demonstrates that *Phytophthora ramorum* has been disseminated through movement of nursery stock from western to eastern States (Goss et al., 2009a). There have been at least four global migrations: NA1 to US; NA2 to US; EU1 to US; and EU1 to Europe (Goss et al., 2009b). Of the three lineages known to be present in the US, NA1 is the most common and the most genetically diverse (Goss et al., 2009a; Mascheretti et al., 2008; Prospero et al., 2009). The California populations are genetically distinct from those in Oregon and Washington. Nursery populations in other States originated in California or the Northwest (Goss et al., 2009b).

The most commonly identified clonal lineage in Washington State is now EU1. Between 2004 and 2009 the population structure of *Phytophthora ramorum* isolates in Washington nurseries, landscapes and waterways has changed, NA1 becoming the least, rather than the most common lineage. In 2005, the NA1 lineage comprised 86% of the population recovered, in 2009 only 10% of the isolates recovered were NA1. At four of the five sites in which EU1 was detected, NA1 was found at the same time[1]. Such shifts in population structure increase the risk of introduction of EU1 or NA2 clonal lineages to new areas in the US.

In Canada, all three clonal lineages of *Phytophthora ramorum* have been present in nurseries at least since 2004. Of these NA2 is the most common (Goss et al., 2011).

The three known *Phytophthora ramorum* lineages are thought to originate from a common ancestor and to have separated approximately 165 000 to 500 000 years ago. Their genetic structure suggests that the presence of *P. ramorum* in North America and Europe has resulted from three independent migration events (Goss et al., 2009b).

Resources

Several compilations of information about forest Phytophthoras have been produced by Cline et al. (2008), Grünwald (2010) and Kang (2010). Grünwald (2010) and Kang (2010) include molecular sequencing data.

Changes to forest Phytophthora control policy and programmes

United States

A Federal Order (USDA APHIS, 2009) prohibiting the importation of *Alnus* spp. (excluding seed) into the US was issued in June 2009. This was designed specifically to prevent introduction of *Phytophthora alni*.

In June 2009, South Carolina implemented State Regulations 27-78 relating to the importation of *Phytophthora ramorum* host plants from California,

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TABLE 3: Additions to the Associated Host List for *Phytophthora ramorum*, 2007 to February 2010.

Host	**Common name**	**Year and Reporter** §
Arctostaphylos uva-ursi	kinnikinnick	2007, Washington State Department of Agriculture
Berberis diversifolia = Mahonia aquifolium	Oregon grape	2007, CFIA
Cercis chinensis	Chinese redbud	2008, CFIA
Choisya ternate	Mexican orange	2008, FERA
Cornus kousa	Kousa dogwood	2008, CFIA
Corylopsis spicata	spike witch hazel	2007, CFIA
Daphniphyllum glaucescens		2008, CFIA
Garrya elliptica	silk tassel tree	2007, FERA
Ilex aquifolium	European holly	2009, FERA
Lithocarpus glaber	Japanese oak	2009, FERA
Magnolia cavalieri	michelia	2009, CFIA
Magnolia denudata x salicifolia	magnolia	2008, FERA
Magnolia figo	banana shrub	2008, California Department of Food & Agriculture
Magnolia foveolata	michelia	2009, CFIA
Magnolia kobus	*Kobus magnolia*	2008, CFIA
Magnolia liliiflora = Magnolia quinquepeta	purple magnolia	2008, FERA
Magnolia salicifolia = Magnolia proctoriana	anise magnolia	2008, FERA
Magnolia x thompsoniana, Magnolia tripetala, Magnolia virginiana	magnolia	2008, FERA
Osmanthus delavayi	Delavay tea olive	2007, Washington State Department of Agriculture
Physocarpus opulifolius	ninebark	2007, CFIA
Prunus laurocerasus	English laurel	2007, Washington State Department of Agriculture
Ribes laurifolium	bay leaf current	2009, FERA
Vaccinium myrtillus	bilberry	2009, FERA
Vaccinium vitis-idaea	lingonberry	2009, FERA

§ CFIA is the Canadian Food Inspection Agency; FERA is the UK Food and Environment Research Agency

Oregon, or Washington nurseries. In March 2010, nursery-associations from these western states challenged the requirements for the inspection and phytosanitary certification of each shipment of host or associated host plants. The court case was stayed in April 2010 when South Carolina agreed to discontinue enforcement of the disputed regulations (California Association of Nurseries and Garden Centers, 2010; Christel Harden, South Carolina Department of Plant Industry, personnal communication, January 9, 2011). In June 2010, USDA APHIS issued a Federal Order requiring States receiving shipments of host plant material from nurseries located in quarantined or regulated areas to be notified in advance of shipment. This Order was rescinded and is currently (January 2011) pending (COMTF, 2010).

A response plan for incursion of *Phytophthora kernoviae* Brasier, Beales & S.A.Kirk (Benson et al., 2008) was produced as part of the National Plant Disease Recovery System requested in Homeland Security Presidential Directive No. 9. The purpose of the plan is to identify the availability of tools, infrastructure, communication networks, and capacity for mitigation of the impact of disease outbreaks. A response plan for “Tree and other ornamental Phytophthoras” is being developed.

The *Phytophthora ramorum* USDA APHIS Response Protocol for Forest and Wildland Environments Version 1.0 (issued June 16, 2006 and updated November 21, 2008[2]) was dropped from the USDA APHIS *P. ramorum* Regulation[3] and there is currently no Federal response

[2] *formerly posted as: http://www.aphis.usda.gov/plant_health/plant_pest_info/pram/downloads/pdf_files/forestwildlandprotocol.pdf, cited in Oregon Department of Agriculture (Oregon Department of Agriculture (ODA), 2009)*

[3] *http://www.aphis.usda.gov/plant_health/plant_pest_info/pram/downloads/pdf_files/7cfr30192-11.pdf*

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protocol for new wildland incursions. Observance of nursery, residential and landscape response protocols is required (USDA APHIS, 2010c).

The first research site in the United States dedicated to the study of pests and diseases affecting ornamental plants, the National Ornamentals Research Site at the Dominican University of California, opened in 2009. Here the primary research focus is *Phytophthora ramorum*. Funded under the 2008 Farm Bill, the site is administered through the USDA APHIS Plant Protection and Quarantine Center for Plant Health Science and Technology (Johnson-Brousseau et al., 2011).

Canada

Canada adopted compensation rules for plant growers (*Phytophthora ramorum* Compensation Regulations, SOR/2007-135, June 7, 2007), setting aside more than US$ 24 million for wholesale and retail nurseries and individuals facing the consequences of eradication procedures.

The Canadian Food Inspection Agency issued a new Risk Assessment for *Phytophthora ramorum* in 2009. The principal conclusions were that the fungus is only likely to cause disease in south coastal British Columbia. Here the risk is considered to be at a medium level. The likelihood of importation remains high and the pathogen continues to have quarantine pest status in Canada (Kristjansson & Miller, 2009).

Central and South America

Central and South America remain largely unexplored territory for forest Phytophthoras. Previous IUFRO Proceedings (Hansen 2000, 2003) summarised recent reports, including destructive impacts of *Phytophthora cinnamomi* Rand in Mexican oak forests (Tainter et al., 2000) and *Phytophthora palmivora* E.J.Butler in Ecuadoran balsawood plantations (Tainter et al., 2003) and these pathogens persist in those areas.

Phytophthora austrocedrae was formally described as the cause of the fatal disease of the Andean native conifer *Austrocedrus chilensis* (D.Don.) Pic. Serm. & Bizarri known as “mal del cipres” (Gresleben & Hansen, 2007). Research continues in Esquel, Argentina, with demonstration of pathogenicity (Greslebin et al., 2010) and further documentation of ecological associations. *Phytophthora austrocedrae* must be considered as one of the most destructive of forest Phytophthoras, at least on its only-known host.

In central Chile, in 2006, another new *Phytophthora* species, *P. pinifolia* caused one of the most dramatic disease epidemics ever recorded (Durán et al., 2008). The disease, (called Daño foliar del pino”) is a foliar blight of planted Monterey pine, *Pinus radiata.* The fungus is unusual in that it is phylogenetically related to benign species in ITS Clade 6. Its aerial habit compared with that of mostly aquatic relatives and its pathogenicity to Monterey pine is also unusual. Intensive research at Bioforest S.A. (a Chilean subsidiary of the Arauco Group) and FABI in South Africa has focused on etiology, epidemiology, and control. Currently, progress on understanding the disease is hampered by the apparent collapse of the epidemic.

Conclusions

Knowledge about forest Phytophthoras in the Americas has increased during the period 2007 – 2010. Further tree mortality was noted, and eradication efforts deployed. Tools and attitudes relating to spread of these fungi need to be refined. Little information exists about the distribution or impact of most forest Phytophthoras in Central and South America, although it is known that death of high-value trees can be caused by *P. cinnamomi*, *P. pinifolia* and *P. austrocedrae.*

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