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Nursery Guide for Diseases Caused by *Phytophthora ramorum* on Ornamentals: Diagnosis and Management

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INTRODUCTION

Phytophthora ramorum, a newly discovered plant pathogen, has caused widespread mortality in native oaks and tanoaks in many coastal areas of central and northern California and in southwestern Oregon. On oaks, the disease is commonly called sudden oak death because trees typically appear to die rapidly (fig. 1) In infested wildlands (forests and woodlands), the pathogen has been detected on several other trees, shrubs, vines, and herbaceous native plants, where it causes less-destructive leaf blights, stem cankers, and tip dieback.

Camellias, rhododendrons, and other popular ornamental plants are susceptible to *P. ramorum* infection, and the pathogen can be moved long distances through shipments of infected nursery stock. By the end of 2004, the pathogen has been detected on nursery stock and some outplantings in 21 U.S. states and British Columbia. Federal and state quarantines are in effect that require nursery inspections, and if the pathogen is found, affected nursery stock must be destroyed as a means of eradication.

Figure 1. Coast live oak mortality, Santa Cruz County, CA, 1999. Photo: S. Tjosvold.

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In Europe, the pathogen has been known for many years to cause similar leaf spot and twig dieback diseases, but there it occurs primarily on ornamental plants in nurseries and gardens. It has been tracked from infected nursery outplantings to neighboring shrubs, and on to cause lethal infections of adjacent trees. This ability to spread heightens the concern that infected nursery stock could move the pathogen to new areas and cause wildland infestations.

In addition to providing a brief description of the history and biology of the pathogen, this publication contains photos and descriptions of symptoms of *P. ramorum* infection on ornamental plants that will aid in plant inspection and early detection in nurseries. The publication also suggests nursery management practices to help prevent the introduction and development of the disease in nurseries.

BACKGROUND

Disease Occurrence on Wildland Hosts in the United States

Sudden oak death was first detected on the central California coast in the mid-1990s. Tens of thousands of tanoaks *(Lithocarpus densiflorus)*, California black oaks *(Quercus kelloggii)*, and coast live oaks *(Quercus agrifolia)* have died since then due to *P. ramorum* infection. In Marin, Santa Cruz, and Monterey Counties, portions of the wildland-urban interface forest changed dramatically as tree crowns turned brown in a few weeks, giving the impression of instantaneous mortality.

In summer 2000, an unknown *Phytophthora* species was isolated from the dying trees, shown to have caused the mortality, and recognized as the same organism as an unnamed *Phytophthora* species found on European nursery and garden plants in 1993. The pathogen was named *Phytophthora ramorum* in 2001.

Figure 1A. Map showing the 14 counties in California in which *P. ramorum* has been found as of March 2005.

As of summer 2004, *P. ramorum* has been detected in wildlands in 14 counties in California and in Curry County, southwestern Oregon (fig. 1A). Symptoms range from lethal bark cankers on several oak species and tanoak to leaf spots and twig dieback on native rhododendrons. It has been found in three broad forest types: California mixed-evergreen forests dominated by coast live oak, redwood forests with tanoak understory, and Oregon forests dominated by tanoak. Table 1 lists plants known to be susceptible as of summer 2004. A current list of susceptible plants—wildland and ornamental hosts—can be found at the California Oak Mortality Task Force Web site, http://www.suddenoakdeath.org.

Disease Occurrence on Ornamentals in the United States and Canada

In January 2001, *P. ramorum* was officially detected on rhododendron plants in a Santa Cruz County nursery located in a forest with many susceptible species and surrounded by dead and dying oak and tanoak trees. Two years later, in 2003, *P. ramorum* was detected in several relatively small nurseries in Santa Cruz County, the Bay Area, the Central Valley, and Placer County, California, and in the Pacific Northwest in Oregon, Washington, and British Columbia. In the spring of 2004, *P. ramorum* was detected in two large nurseries in southern California and Oregon, and infected camellia and rhododendron nursery stock was shipped to many locations throughout the United States and Canada. By the end of 2004, the pathogen has been detected on nursery stock from traced shipments, outplantings, and survey in 21 states and British Columbia.

Disease Occurrence on Ornamentals and Native Hosts in Europe

In 1993, rhododendrons and viburnums in Germany and the Netherlands showed twig dieback, cankers, and leaf spots. The unrecognized *Phytophthora* species isolated from the plants was largely ignored until 2000, when the morphologically similar organism associated with oak and tanoak mortality in California was discovered.

By 2004, the pathogen had been found in over 400 European nurseries and public gardens in 9 countries on 13 genera. Most of the diseases found on these ornamental species are covered in this publication. Until late 2003, *P. ramorum* had been found only in plant nurseries and gardens and not on native trees. However, beech, horse chestnut, turkey oak, sweet chestnut, and Holm oak in woodland settings have been found to be infected at multiple sites in England. These sites were associated with previously identified infected rhododendron plantings. Infected red oaks, an important forest and lumber species native to the eastern United States, have been found in gardens in the Netherlands and the United Kingdom and were associated with infected rhododendrons planted nearby.

BIOLOGY

Phytophthora ramorum, while having many features in common with fungal organisms, is not a true fungus. Technically it belongs in the kingdom Chromista (also known as Straminipila), related to diatoms and brown algae. *Phytophthora* species are oomycetes, or water molds, and require a moist environment to actively grow and reproduce. The genus *Phytophthora* has over 60 species, many of which are important plant pathogens. The body of the organism is

Table 1. Wildland plants known to be susceptible to *Phytophthora ramorum* in the United States, summer 2004

Scientific name	Common name	Plant part(s) affected
Abies grandis	grand fir	twig
Acer macrophyllum	bigleaf maple	foliar
Aesculus californica	California buckeye	foliar
Arbutus menziesii	madrone	foliar and twig/branch
Arctostaphylos manzanita	manzanita	foliar and twig
Corylus cornuta	California hazelnut	foliar
Heteromeles arbutifolia	toyon	foliar and twig/branch
Lithocarpus densiflorus	tanoak	trunk/foliar and twig
Lonicera hispidula	California honeysuckle	foliar
Pseudotsuga menziesii var. *menziesii*	Douglas-fir	twig
Quercus agrifolia	coast live oak	trunk
Quercus chrysolepis	canyon live oak	trunk
Quercus kelloggii	California black oak	trunk
Quercus parvula var. *shrevei*	shreve oak	trunk
Rhamnus californica	California coffeeberry	foliar
Rhamnus purshiana	cascara	foliar
Rhododendron macrophyllum	Pacific rhododendron	foliar and twig/branch
Rosa gymnocarpa	wood rose	foliar
Rubus spectabilis	salmonberry	foliar
Sequoia sempervirens	coast redwood	foliar and twig
Toxicodendron diversiloba	poison oak	twig/branch
Trientalis latifolia	western starflower	foliar
Umbellularia californica	California bay laurel/ pepperwood/Oregon myrtle	foliar
Vaccinium ovatum	evergreen huckleberry	foliar and twig/branch

Table 2. Common Rhododendron species and cultivars infected by *Phytophthora ramorum* by July 2004

R. augustinii
R. 'Anah Kruschke'
R. 'Baden Baden'
R. 'Bambino'
R. 'Besse Howells'
R. brachycarpum
R. catawbiense
R. 'Catawbiense Boursault'
R. 'Chinoides'
R. 'Cunningham's White'
R. 'Dora Amateis'
R. 'Elizabeth'
R. 'English Roseum'
R. 'Everestianum'
R. 'Gomer Waterer'
R. 'Holden'
R. 'Lem's Storm Cloud'
R. 'Lord Roberts'
R. macrophyllum
R. 'Mrs. Furnivall'
R. 'Nancy Evans'
R. 'Nova Zembla'
R. 'President Roosevelt'
R. 'Purple Splendour'
R. 'Roseum Elegans'
R. 'Scintillation'
R. 'Unique'
R.'Vulcan'

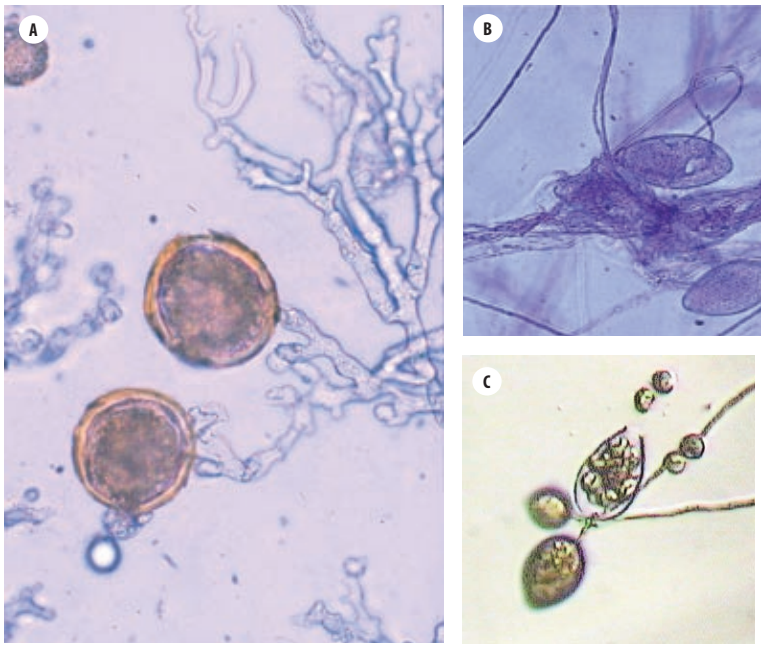

Figure 2. Chlamydospores (A), sporangia (B), and sporangium with zoospores (C) of *P. ramorum*. Photos: D. Rizzo.

made up of threadlike strands; each strand is called a hyphae, and the strands are collectively called mycelium. Mycelium grows through leaf, bark, and vascular tissue.

Phytophthora ramorum produces several reproductive structures important for pathogen spread and survival, including sporangia, zoospores, and chlamydospores (fig. 2). Sporangia give rise to the zoospores, which are biflagellate spores that can swim in water. Chlamydospores are resting spores that help the pathogen survive extreme temperatures, dryness, and other harsh conditions. *Phytophthora ramorum* can grow within a temperature range of 36° to 80° F (2.2° to 26.7°C), with an optimum temperature of 68° F (20°C).

These spore structures commonly form on leaf surfaces of susceptible leaves and twigs following prolonged wetting. They are moved in contaminated soil and from plant to plant via windblown rain or by direct contact of infected leaves. In California forests the pathogen sporulates prolifically on California bay laurel trees *(Umbellularia californica)* that serve as reservoirs for inoculum (fig. 3). Infected California bay laurel can also be an important source of inoculum when in close proximity to nursery stock.

Figure 3. Symptoms of *P. ramorum* infection on California bay laurel leaves. Photo: S. Tjosvold.

Phytophthora ramorum is heterothallic, meaning that sexual reproduction can occur only between two different mating types, called A1 and A2. The European *P. ramorum* genotype is predominantly an A1 mating type, and the North American genotype is A2. Oospores, the sexual spore, which can result from the union of A1 and A2 strains, have not been observed under natural conditions. However, the European mating type has been found in two Pacific Northwest nurseries and one Canadian nursery; and in two other Pacific Northwest nurseries (under the same ownership), both the North American A2 and European A1 strains were found. This raises concerns that both mating types might eventually meet and reproduce sexually to create new, potentially more virulent strains capable of exploiting new habitats and host species.

There may be differences in virulence and symptom expression between the European and North American genotypes. The symptoms described in this guide for rhododendron, camellia, viburnum, pieris, Douglas-fir, and grand fir are based on observations of plants infected with the North American genotype. The disease descriptions given in this guide for other ornamentals are based on observations of European plants infected with the European genotype.

Table 3. Common Camellia cultivars found to be infected by *Phytophthora ramorum* on two or more occasions as of July 2004

C. japonica 'Bob Hope'
C. japonica 'Daikagura' var. *C. japonica* 'Debutante'
C. japonica 'Elegans Splendor'
C. japonica 'Glen 40'
C. japonica 'Kumasaka'
C. japonica 'Kramer's Supreme'
C. japonica 'Mathotiana Supreme'
C. japonica 'Mrs. Charles Cobb'
C. japonica 'Nuccio's Gem'
C. japonica 'Nuccio's Pearl'
C. japonica 'Silver Waves'
C. japonica 'Shiro Chan'
C. japonica 'Tom Knudsen'
C. oleifera 'Winter's Fire'
C. sasanqua 'Apple Blossom'
C. sasanqua 'Cleopatra'
C. sasanqua 'Hana Jiman'
C. sasanqua 'Jean May'
C. sasanqua 'Kanjiro'
C. sasanqua 'Setsugekka'
C. sasanqua 'Yuletide'

SYMPTOMS ON ORNAMENTAL NURSERY HOSTS

Although hosts of *P. ramorum* show a range of symptoms, in general the disease is characterized by irregular necrotic leaf lesions, rather than distinct leaf spots. Leaf infections can develop down the petiole and into twigs. Often, infected leaves fall off before the lesion reaches the petiole. Infections may occur initially on stems or move into stems and cause blights in which stems and associated leaves wilt, become necrotic, and die. A distinct dark line can mark the advance of the infection on some species, such as California bay laurel. Under natural conditions, California bay laurel tends to get infected on the tip of the leaf, where the leaf hangs down and water accumulates (see fig. 3). This characteristic is seen in some nursery hosts as well. Infection often occurs in leaf areas where free water remains on leaves for long periods, such as deep in the leaf canopy, near or touching the soil, and between overlapping or cupped leaves.

Symptoms caused by fertilizer burn, chemical injury, drought injury, freeze damage, sunburn, and root damage can resemble *P. ramorum* infection. The best way to distinguish this abiotic damage on foliage from damage caused by plant diseases, including *P. ramorum,* is to check the underside of the leaf and the lesion margins. In abiotic injury, margins of the lesions are abrupt and distinct, not diffuse. Environmental problems, flooding, or openings in nursery shade cloth may explain the plant damage. Abiotic injury is often found distributed over the entire plant, while *P. ramorum* leaf spots are often found on only a few leaves or on one portion of the plant.

This following sections present detailed descriptions of *P. ramorum* symptoms on ornamental plants and Christmas tree stock. Native plant nurseries should use pictures and descriptions of symptoms on native plants (see Davidson et al. 2003).

RHODODENDRON (ERICACEAE)

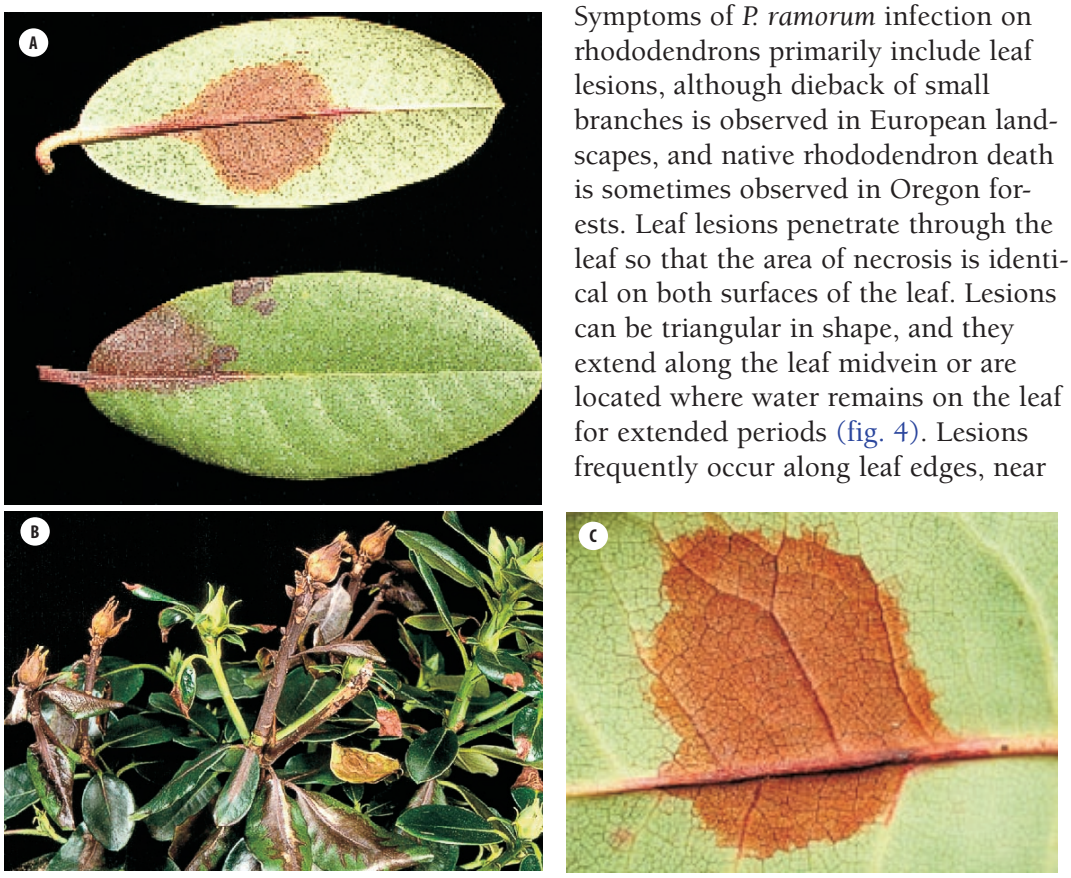

Figure 4. Symptoms of *P. ramorum* infection on rhododendron. (A and C): Leaf lesions on *R.* 'Todmorden.' Photo: S. Tjosvold (B): Stem and bud necrosis on a rhododendron from Germany. Photo: S. Werres.

Symptoms of *P. ramorum* infection on rhododendrons primarily include leaf lesions, although dieback of small branches is observed in European landscapes, and native rhododendron death is sometimes observed in Oregon forests. Leaf lesions penetrate through the leaf so that the area of necrosis is identical on both surfaces of the leaf. Lesions can be triangular in shape, and they extend along the leaf midvein or are located where water remains on the leaf for extended periods (fig. 4). Lesions frequently occur along leaf edges, near

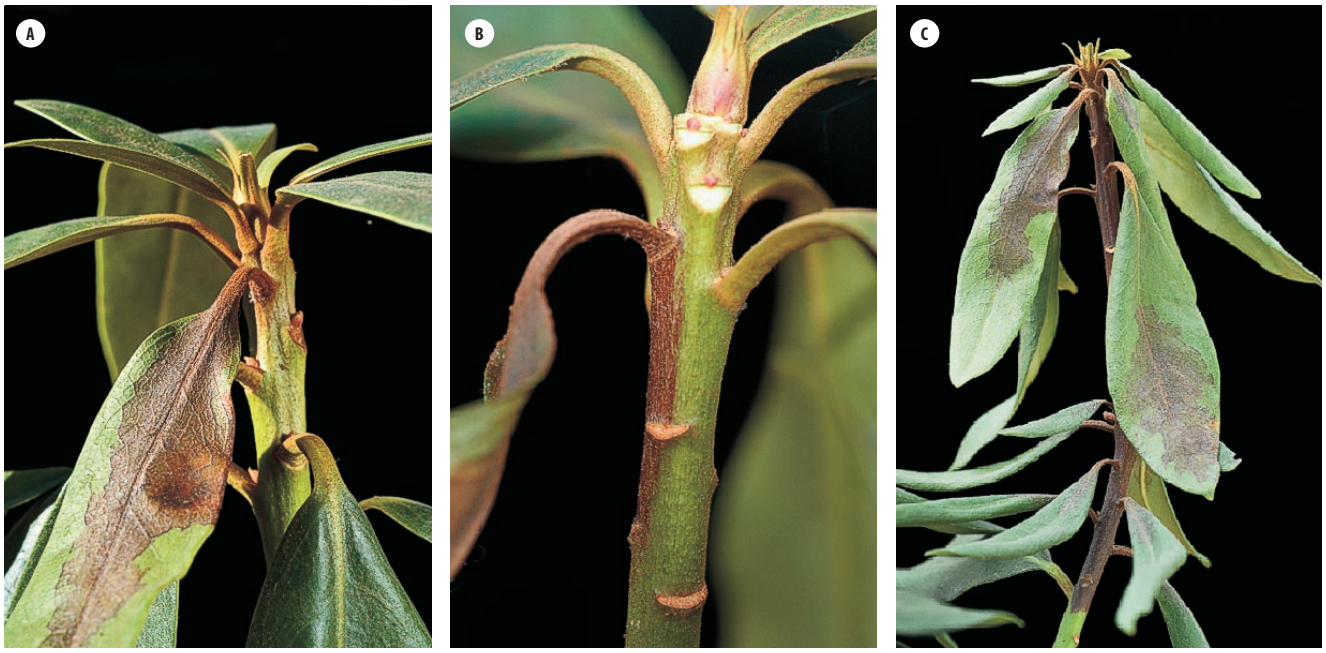

Figure 5. Symptom progression during approximately 3 weeks on a laboratory-infected *R.* 'Cunningham's White.' (A): Initial leaf infection sites. Infection develops through petiole, forming stem canker (B). Infection develops upward and downward in stem, and into leaf petioles and bases of leaves (C). Photos: S. Tjosvold.

the petiole and at the leaf tip. During an active infection, lesion margins have diffuse edges that become less diffuse and more distinct as the weather becomes warmer and drier. Infected leaves may fall prematurely from the plant. Infections of small branches produce brown to black cankers. Leaves located distally to the cankers can wilt, roll, and eventually defoliate due to lack of water. Infections can move up or down a branch and into a leaf base (fig. 5).

By July 2004, many different rhododendron species and cultivars had been found to be infected in the United States; of those, table 2 lists the most common.

Azaleas have not been found to be infected with *P. ramorum* in a nursery situation, but laboratory inoculation studies indicate that some azaleas, particularly deciduous azaleas, are susceptible (*R.* 'Northern Hi-Lights'), and the California native *Rhododendron occidentale* has been found to be infected in wildland situations.

Diseases and conditions that may cause leaf necrosis and may be confused with *P. ramorum* infection include other *Phytophthora* species that infect the aerial portion of rhododendrons, including *P. cactorum, P. citricola, P. hibernalis, P. nicotianae (= P. parasitica)*, and *P. syringae*. Abiotic factors that can cause leaf necrosis include chemical injury, drought, cold, sunscald, and fertilizer burn (fig. 6). Wilting and death of an entire plant is more likely caused by root weevils or root-infecting *Phytophthora* species, not *P. ramorum*.

CAMELLIA (THEACEAE)

Symptoms of *P. ramorum* infection on camellias are limited to leaf lesions that vary in size from 0.2 inch (0.5 cm) in diameter to covering nearly half the leaf, depending on environmental conditions (figs. 7–12). Lesions are located primarily at the leaf tip or the edge of the leaf. The lesions can be surrounded by diffuse margins or thick black zone lines. Infected leaves abscise prematurely, and the lower part of the plant can defoliate. Tip dieback or small branch cankers caused by *P. ramorum* have not been observed on *Camellia* species under nursery conditions.

Figure 6. Leaf necrosis on rhododendron leaves caused by unknown noninfectious disorders. Photos: S. Tjosvold.

By July 2004, over 150 *Camellia* species and cultivars had been found to be infected in the United States. Table 3 contains lists cultivars on which *P. ramorum* was isolated from nursery stock on two or more occasions.

Few other diseases are likely to be confused with *P. ramorum* on camellias. Scorch symptoms are most commonly confused with *P. ramorum* infection on certain camellia varieties in areas that receive reflective heat and sun on the exposed leaves of the plant (fig. 13). *Pestalotia* and *Pestalotiopsis* species can act as weak secondary pathogens following leaf scorch and can cause necrosis.

Table 4. Pieris species and cultivars confirmed infected with *Phytophthora ramorum*

P. floribunda × japonica
P. formosa var. *forrestii*
P. formosa var. *forrestii* × *P. japonica*
P. formosa × japonica
P. japonica 'Flaming Silver'
P. japonica × formosa
P. japonica 'Variegata'

PIERIS (ERICACEAE)

Symptoms of *P. ramorum* on *Pieris* (andromeda) species and cultivars (table 4) include necrotic leaf spots similar to those on rhododendron, as well as branch tip dieback (figs. 14 and 15). Infected leaves often abscise prematurely.

Other diseases of pieris include those caused by aerial *Phytophthora* species that cause leaf lesions similar to *P. ramorum*. *Phytophthora* species such as *P. citricola* and *P. nicotianae* (= *P. parasitica*) also cause root rots in pieris, but these are likely to affect the whole plant rather than individual leaves or twigs. Initial symptoms on new growth can resemble those caused by *Botrytis* species.

Figure 7. Symptoms of *P. ramorum* infection on camellia. Photo: PHSI Defra, UK.

Figure 8. Symptoms of *P. ramorum* infection on *Camellia sasanqua* 'Bonanza.' Photo: C. Blomquist.

Figure 9. Symptoms of *P. ramorum* infection on *Camellia japonica* 'Mrs. Charles Cobb.' Photo: C. Blomquist.

Figure 10. Infected *C. japonica* × *saluenensis* 'Coral Delight.' Photo: C. Blomquist.

Figure 11. Infected *C. japonica* 'Kumasaka.' Note sparse foliage due to leaf abscission. Photo: C. Blomquist.

Figure 12. Limited leaf lesions on *C. sasanqua* 'Bonanza' in a dry climate. Photo: S. Jordan.

Figure 13. Symptoms of sun scorch on camellia. Photo: T. Pastalka.

Figure 14. Branch tip dieback on *Pieris japonica* 'Variegata.' Photo: N. Osterbauer.

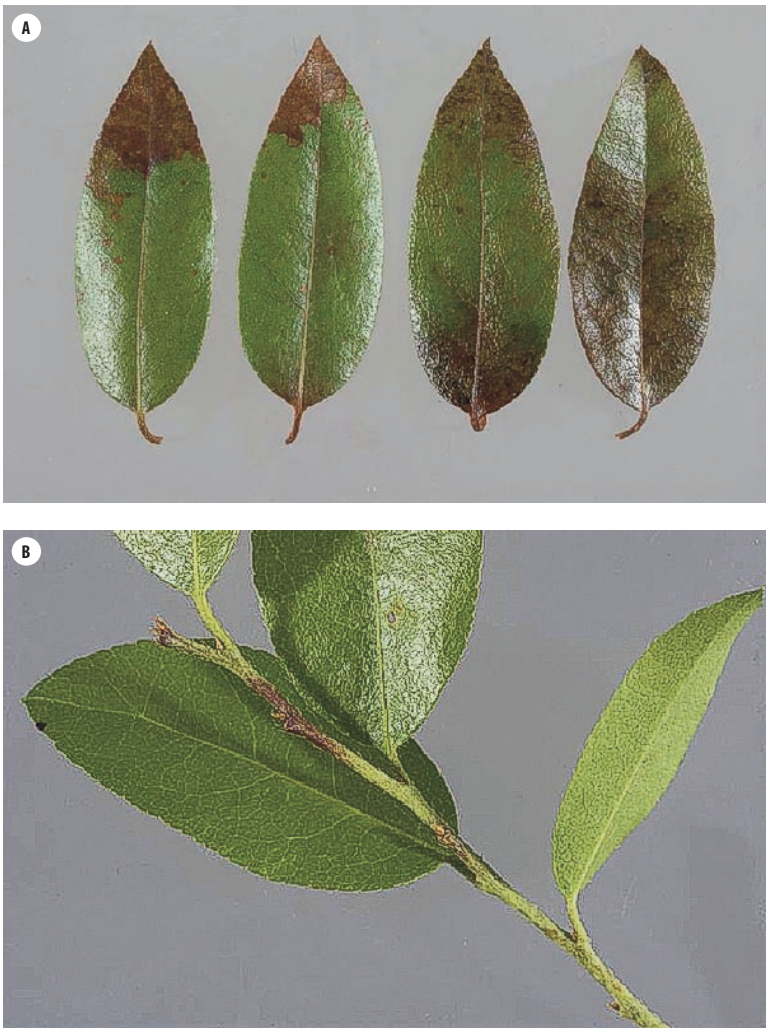

Figure 15. *Phytophthora ramorum* leaf (A) and stem (B) lesions on pieris. Photos: PHSI Defra, UK.

VIBURNUM (CAPRIFOLIACEAE)

Symptoms of *P. ramorum* on *Viburnum* species (table 5) include stem cankers and/or necrotic leaf lesions (figs. 16–18). Stem cankers can occur at the base of the plant close to the soil line or on smaller branches throughout the plant canopy. As a stem canker grows, leaves normally attached to the stem in the canker area die and drop from the plant. As the stem becomes girdled by the canker, the leaves located between the canker and the stem tip wilt and eventually turn brown. These brown leaves usually stay attached to the stem. Leaf infections occur initially on the leaf tip, edge, or petiole. Infection can grow through the leaf, into the leaf petiole, and into the stem to form a canker.

Table 5. *Viburnum* species and cultivars confirmed to be infected with *Phytophthora ramorum*

V. × *bodnatense*
V. × *burkwoodii*
V. × *carlcephaleum*
V. davidii
V. farreri (= *V. fragrens*)
V. lantana
V. opulus
V. plicatum
V. plicatum f. *tomentosum*
V. pragnense
V. 'Schneewolke'
V. tinus
V. utile

Other diseases or conditions whose symptoms resemble infection include frost damage, which can cause the blackening of young shoots and dieback. Whole plants can wilt due to drought, anaerobic conditions caused by overwatering, or root diseases caused by other *Phytophthora* species.

KALMIA (ERICACEAE)

Symptoms on *Kalmia* (mountain laurel) species have been found only on leaves (fig. 19). The disease is manifested as necrosis along the leaf margins and down the midvein.

Figure 16. *Phytophthora ramorum* stem (A) and leaf (B) lesions on *Viburnum tinus.* Photos: C. Blomquist.

Figure 17. Tip dieback in *Viburnum plicatum tomentosum* caused by *P. ramorum.* Photo: Oregon Department of Agriculture.

Figure 18. Stem lesion in viburnum caused by *P. ramorum.* Photo: PHSI Defra, UK.

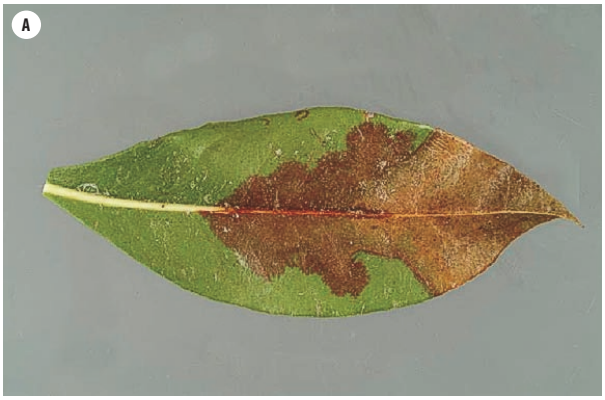

Figure 19. *Kalmia latifolia* leaves infected with *P. ramorum.* Photos: PHSI Defra, UK.

Figure 20. Leaf lesions caused by *P. ramorum* on leucothoe. Photo: PHSI Defra, UK.

Kalmia latifolia is the only species to have been found to be infected by *P. ramorum*: *K. latifolia* 'Big Boy Pink' and 'Olympic Fire' were found to be infected in the United States as of July 2004. *Kalmia angustifolia* has been shown in laboratory studies to be resistant to *P. ramorum*.

Two other diseases known to cause leaf spotting in mountain laurel are one caused by *Mycosphaerella colorata,* whose symptoms are small silver to white spots, and one caused by *Phomopsis kalmiae,* whose symptoms are round brown lesions with a distinct zone line, as opposed to the single amorphous necrotic lesion caused by *P. ramorum*.

LEUCOTHOE (OLEACEAE)

Symptoms observed on *Leucothoe* species tend to begin at the leaf tips. The pathogen subsequently grows through the leaf tissues toward the leaf base, causing a brown to black discoloration (fig. 20). No stem cankers have been observed.

The only cultivar found to be affected is *L. fontanesiana* 'Rainbow,' and no other cultivars have been tested for resistance.

Another disease that can cause leaf lesions in *Leucothoe* species is caused by *Cylindrocladium* spp., but unlike *P. ramorum,* it can girdle and kill stems.

Figure 21. Symptoms of *P. ramorum* infection on lilac. Photos: A. Schlenzig.

SYRINGA (OLEACEAE)

Symptoms on *Syringa* (lilac) species include leaf lesions along the edges of leaves and the death of leaf buds before opening, which results in the appearance of dieback (fig. 21).

Cultivars found to be infected include *Syringa vulgaris* 'Belle de Nancy,' 'Katherine Havermeyer,' and 'Common Purple.'

Other diseases of lilac include bacterial shoot, stem, and leaf blight caused by *Pseudomonas syringae*. Bacterial blight affects the new, succulent growth of lilac leaves and shoots in cool, wet conditions. Infected new tissue turns soft and black, and infected leaves remain attached to the stem. Blight caused by *Ascochyta syringae* affects lilac shoots and flower stalks, but the pathogen forms fruiting bodies that are visible with a hand lens, while no structures are visible on *P. ramorum*-infected tissue. Both bacterial and Ascochyta blight can affect lilac stems, whereas *P. ramorum* primarily affects lilac leaves.

OTHER HOSTS

In Europe, isolated instances of *P. ramorum* infections have also been found in other nursery stock. These include containerized yew *(Taxus baccata)* in the United Kingdom, causing leaf and stem dieback; and strawberry tree *(Arbutus unedo)* in Spain, where symptoms resemble the large leaf lesions on its Pacific coast relative madrone *(Arbutus menziesii)*.

Figure 22. Tip dieback in grand fir Christmas tree stock. Photo: M. Nachand.

PHYTOPHTHORA RAMORUM IN CHRISTMAS TREE PLANTATIONS

Phytophtora ramorum can infect newly expanding branch tips of Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) and grand fir *(Abies grandis)* (fig. 22). Christmas tree plantations must be inspected in the spring during the period of new shoot elongation and again prior to harvest. Precautions must be taken to prevent the introduction and establishment of the pathogen into areas and species where it does not presently occur.

To date, Douglas-fir and grand fir have been found to be infected only where they are grown underneath heavily infested California bay laurel. It appears that close proximity to California bay laurel or another source of inoculum is necessary for infection of these coniferous species. Tree plantations should be inspected for the presence of California bay laurel and other hosts, and Christmas trees grown under them should be checked for tip dieback. Infected California bay laurel trees near the perimeter of tree plantations may produce inoculum that can spread and infect nearby host plants. Removal of California bay laurel trees may be warranted.

QUARANTINES, REGULATIONS, AND OFFICIAL INSPECTIONS

Movement of *P. ramorum* hosts is regulated by several states, Canada, Mexico, the European Union, Czech Republic, South Korea, Australia, and New Zealand. Since January 2005, a new federal order regulates interstate movement of nursery stock from uninfested areas in California, Oregon, and Washington. Under the new federal order, all nurseries must be inspected and found free of *P. ramorum* before they can ship nursery stock interstate. Regulatory officials perform the inspections, sampling, and testing according to the procedures described in the federal order. In the regulations, "hosts" are defined as species that are naturally infected by *P. ramorum*; scientific steps have been completed to confirm pathogenicity (Koch's postulates), and designation as a host is scientifically reviewed and accepted. "Associated hosts" are defined as species that are naturally infected and in which *P. ramorum* has been cultured and/or detected using PCR (see the section "Sampling and Diagnosis," below), but Koch's postulates have not been completed or documented and scientifically reviewed and accepted.

Regulations are continually updated to reflect new findings on *P. ramorum*'s host range and mode of spread. For complete information on regulated hosts and regulations, see the USDA APHIS Plant Protection and Management Program *Phytophthora ramorum* Web site at http://www.aphis.usda.gov/ppq/ispm/pramorum/ or consult your local county agricultural commissioner's office or state agriculture department.

NURSERY INSPECTION AND SCOUTING

Systematic and careful inspection of nursery crops and propagative plant material is essential to prevent introduction of *P. ramorum* and limit its spread within and from contaminated nurseries. The pathogen must be detected early, while at very low levels. Nursery operators and agricultural inspectors can take several steps to make inspection less onerous. This discussion focuses on detecting *P. ramorum*; a more comprehensive scouting program is needed for general pest management. For more information on scouting and inspection, see *IPM for Floriculture and Nurseries* (Dreistadt 2001) and *IPM in Practice* (Flint and Gouveia 2001).

A Trained Scout

Designate one nursery staff member as the scout and ask all employees to report unusual related conditions or concerns to the scout. Train the scout to recognize symptoms of *P. ramorum* infection as well as symptoms of other disorders that might mimic it.

Maps and Recordkeeping

A nursery layout map that includes the approximate locations of targeted species is useful for helping the scout get oriented and for developing a scouting strategy. A scouting map that includes species and cultivar names, locations, approximate quantity, and sources of targeted plants in scouted areas should be used in scouting. During scouting, record the date, observations, and sampling information directly onto the scouting map. Review the recorded information and use it to develop a more efficient scouting strategy each time the nursery is scouted.

Systematic Inspection

Begin an inspection with an overview of the area from the crop perimeter or with a quick walk-through. If suspicious symptoms are apparent, immediately examine them more closely to attempt to identify the problem. If no symptoms are apparent, walk a systematic path through the crop. A common scouting technique is to move relatively quickly down a walkway and scan both sides of adjacent production beds, back and forth. If suspicious symptoms are seen, inspect plants more closely. A good-quality 10× hand lens can help identify many tiny pests or early disease symptoms, although *P. ramorum* spores cannot be seen at this magnification.

If plants are found with suspicious leaf spots or other symptoms, collect a sample from the plant (see "Sampling and Diagnosis," below) and mark the plant with plastic tape or a flag and note its location on the scouting map. Additionally, select a few plants at random to closely inspect for early stages of lesion development: look for inconspicuous leaf spots and fallen leaves with characteristic lesions.

Scouting can be prioritized to focus on the highest-risk stock. Closely monitor stock or cuttings of hosts from outside sources. Disease symptoms may take weeks to several months to become apparent, and plants may appear healthy until then. Fungicides that have activity on *Phytophthora* can slow development of new infections and therefore detection, so do not apply these fungicides while evaluating disease status. Note outside-source plants on scouting maps so they can be scouted weekly. Intensify scouting a few weeks after bud break and be especially thorough in rainy periods when environmental conditions are highly conducive to pathogen infection and development. For nurseries surrounded by native hosts, scout areas immediately adjacent to these hosts, especially wet areas, near puddles, or rain runoff zones.

Good Sanitation

Agricultural inspectors and other nursery visitors should take steps to avoid moving contaminated plant material and soil between nurseries. Shoes, tools and vehicle tires should be thoroughly washed of soil and sanitized with a registered disinfectant such as Lysol. Take extra precaution when working in areas known to be infested; disposable overboots may be used and disposed of on-site.

SAMPLING AND DIAGNOSIS

Select a fresh, representative sample of symptomatic plant parts including associated leaves and stems. Place the dry sample in a plastic bag, seal it, and label it with date, genus, species, cultivar, and nursery location. Keep the sample cool and away from direct sunlight, and deliver it to a diagnostic laboratory within 24 hours. *Phytophthora*-specific ELISA test kits (see below) can be used at the nursery to help rule out

Phytophthora species as the cause of disease. Contact your local agricultural commissioner's office for information on where to deliver or send the sample. Once the sample is received at the diagnostic laboratory three laboratory methods can be used to aid diagnosis:

- **ELISA** (enzyme-linked immunosorbent assay, such as used in some field test kits) is used as a quick prescreen to detect many species of *Phytophthora*. An ELISA test specific to *P. ramorum* is not available.
- **PCR** (polymerase chain reaction) uses DNA extracted from plant tissue or laboratory cultures. In PCR, the pattern of the DNA band amplified from the unknown pathogen must exactly match that of known *P. ramorum*.
- **Selective culture media** can be used to isolate *P. ramorum* and other *Phytophthora* species from infected plant tissue. Plant tissue is selected from the leading edge of a canker or lesion and placed in selective media. Morphological characteristics of the mycelium, sporangia, and chlamydospores can be used to aid in identification.

DISEASE MANAGEMENT

For most nurseries, the foremost objective of pest management programs is to prevent the introduction of the pathogen into the nursery via infected plant material or other means. This can be accomplished in part by careful inspection of all incoming host propagative material and stock. Because symptoms are not always readily apparent on stock, a weekly systematic monitoring of stock by a trained nursery scout helps ensure that the pathogen has not been introduced (see "Inspection and Scouting," above). Other helpful practices include:

- Make all nursery personnel aware of the issues and disease symptoms regarding this pathogen and require that they alert the nursery scout or other authority if symptoms are seen.
- Ensure that incoming host plant material from infested counties (the regulated areas) has been properly inspected by agricultural inspectors.
- For high-risk incoming shipments, unload nursery stock in an area that can be cleaned of leafy debris, because infected leaves often drop from plants. Sweep debris from the receiving area and delivery truck and bag for disposal. Loading and delivery areas should be as far from production areas as possible.
- Maintain good shipping and receiving records to facilitate tracing of shipments if contaminated stock is detected.

Nurseries Surrounded by Native Host Trees and Shrubs in the Vicinity Where *P. ramorum* Is Found

- Periodically inspect nearby native hosts for disease symptoms. Infected California bay laurel trees near the perimeter of nurseries may produce inoculum that can spread and infect nearby host plants. Removal of these trees may be warranted.
- Rain runoff coming downslope from areas containing infected hosts may contain *P. ramorum*. Consider building berms to prevent water and soil from moving into production areas from hillsides surrounding the nursery.
- Irrigation water pumped from streams and ponds in areas of infected native hosts may be contaminated with *P. ramorum*. Consider having this water periodically tested to detect *P. ramorum*. If the pathogen is found to be present, use alternative irrigation sources, such as well water, or employ disinfection treatments.

Other Cultural Practices That Can Be Useful to Reduce Disease Risk

- Avoid irrigation practices that wet the foliage for prolonged periods. If sprinklers are used, irrigate in the morning to allow for thorough and quick drying of foliage.
- Monitor and maintain irrigation systems to ensure the most uniform application of water. Correct low spots, areas of poor drainage, and clogged or leaking irrigation heads.
- Monitor irrigation water sources, other than well water, for *P. ramorum*. Use disinfection systems if using recycled water.
- Wounded leaves (even tiny wounds or scratches) are much more susceptible to infection than sound leaves. Avoid handling host plants if they might be wounded when environmental conditions favor disease.
- Avoid soil or container soil contact with foliage, and avoid splashing water from soil onto foliage. Use raised benches, gravel, or other means to elevate susceptible plants above soil. Transplants, even on gravel beds, appear to be very susceptible to disease due to the close proximity of foliage to soil, runoff water, or rain splash. Raised benches may be warranted for transplants.
- Plants or plant parts that are suffering from poor vigor, disorders, or other serious problems should be removed from production areas and destroyed. A small number of plants or plant parts can be bagged and disposed. If a cull pile is needed temporarily, cover the pile with a clear polyethylene sheet until the culls can be destroyed or composted.
- Propagate cuttings only from disease-free hosts.
- Use only new or disinfested containers and soil. Locate piles of potting soil as far from infected native hosts or cull piles as possible, and cover them with clear polyethylene sheeting. Do not mix potting soil components on bare soil.
- Disinfect tools and shoes that have been in contact with contaminated plants or soil (see "Inspection and Scouting," above).

Fungicides

- If fungicides are applied to nursery stock, they should be applied as preventative treatments. Currently, even the most active fungicides do not stop the development of *P. ramorum* once foliar lesions are present. Fungicides must be applied before environmental conditions favor pathogen infection, such as before a period of rainy weather that would allow water to linger on leaf surfaces for many hours. Some fungicides applied to the foliage move into leaves and are not washed off by rain or sprinkler irrigation, while others provide a protective layer of chemical on the leaf surface. Some can be applied to the soil, where they are adsorbed and then move upward to the leaves to protect the leaves from infection. Some have residual activity that can last for several weeks. Read fungicide labels and technical information provided by the manufacturer to learn how the fungicide can be used most effectively.
- The regular and blanket use of fungicides encourages the development of resistant pathogen strains. Fungicides with specific modes of action—as is the case with many *Phytophthora*-active fungicides—are especially likely to promote resistance. Minimizing fungicide use is the best way to prevent resistant strains from developing. If fungicides must be applied, use different chemical classes—either in rotation or by combining products in tank mixes. Fungicides active on *P. ramorum* may already be used in the nursery to control other foliar or soil-inhabiting *Phytophthora* species or related pathogens (such as downy mildews), and their use

should be considered in planning the overall fungicide treatment strategy. For more information on a fungicide treatment strategy for California growers, see the UC Integrated Pest Management Web site at ucipm.ucdavis.edu.

- Fungicides active on *Phytophthora* should not be applied to high-risk nursery stock or cuttings that will be monitored for *P. ramorum* infection because detection of symptoms may be delayed or masked (see "Inspection and Scouting," above).

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BIBLIOGRAPHY

Antonelli, A. L., R. S. Blyther, R. R. Maleiki, S. J. Collman, and A. D. Davidson. 1984. How to identify rhododendron and azalea problems. Pullman: Washington State Univ. Cooperative Extension Publication EB1229.

Canadian Food Inspection Agency, Plant Health Risk Assessment Unit. July 2003. Hosts of *Phytophthora ramorum*. Oak Mortality Task Force Web site, http://www.cnr.berkeley.edu/comtf/pdf/P.ramorum.hosts.June.2003.pdf

Chastagner, G. A. 1997. Christmas tree diseases, insects and disorders in the Pacific Northwest: Identification and management. Puyallup: Washington State University Cooperative Extension.

Coyier, D., and M. Roane. 1986. Compendium of rhododendron and azalea diseases. St. Paul, MN: APS Press.

Davidson, J. M., S. Werres, M. Garbelotto, E. M. Hansen, and D. M. Rizzo. 2003. Sudden oak death and associated diseases caused by *Phytophthora ramorum*. Plant Health Progress doi:10.1094/PHP-2003-0707-01-DG. http://www.plantmanagementnetwork.org/pub/php/diagnosticguide/2003/sod/davidson.pdf. Available by subscription.

Department for Environment, Food, and Rural Affirs (DEFRA) (UK). DEFRA Plant Health Information Sheet: *Phytophthora ramorum*: A potential threat to our trees, woodland and heathland. DEFRA Web site, http://www.defra.gov.uk/planth/pestnote/sudden.htm

Dreistadt, S. H. 2001. IPM for floriculture and nurseries. Oakland: University of California Agriculture and Natural Resources Publication 3402.

———. 2004. Pests of landscape trees and shrubs: An integrated pest management guide. 2nd ed. Oakland: University of California Agriculture and Natural Resources Publication 3359.

Flint, M. L., and P. Gouveia. 2001. IPM in practice: Principles and methods of integrated pest managament. Oakland: University of California Agriculture and Natural Resources Publication 3418.

Ivors, K., et al. 2002. Molecular population analyses of *Phytophthora ramorum*. Abstract. Sudden Oak Death Science Symposium, Monterey, California, December 15–18, 2002. UC Integrated Hardwood Range Management Program Web site, http://danr.ucop.edu/ihrmp/sodsymp/paper/paper17.html

Jones, R. K., and D. M. Benson. 2001. Diseases of woody ornamentals and trees in nurseries. St Paul, MN: APS Press.

Pennsylvania State University Cooperative Extension Plant Disease Web site, http://www.cas.psu.edu/docs/CASDEPT/PLANT/EXTENSION/PLANT_DISEASE/lilac.html

Tjosvold, S. A., et al. 2002. Susceptibility of azalea *(Rhododendron)* to *Phytophthora ramorum*. Abstract. Sudden Oak Death Science Symposium, Monterey, California, December 15–18, 2002. UC Integrated Hardwood Range Management Program Web site, http://danr.ucop.edu/ihrmp/sodsymp/poster/poster45.html

University of Illinois Plant Disease IPM Web site: http://www.ipm.uiuc.edu/diseases/

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