Phytophthora ramorum Werres, de Cock & Man in't Veld

Pest Risk Assessment for Oregon

This risk assessment (PRA) follows the format used by the Exotic Forest Pest Information System for North America. For a description of the evaluation process used, see www.exoticforestpests.org/english/guidelines/eval.htm. A risk assessment for the United States has already been prepared by Dr. John Kliejunas, USDA Forest Service, on 10/22/2001.

IDENTITY
Name: *Phytophthora ramorum* Werrres, de Cock & Man in't Veld
Taxonomic Position: Oomycota: Peronosporales
Common Name: Sudden Oak Death Phytophthora

RISK RATING SUMMARY
Numerical Score: 18
Relative Risk Rating: HIGH
Uncertainty: Moderately Certain
Uncertainty in this assessment results from: At present, the entire host range of this pathogen is unknown. However, *P. ramorum* does naturally infect and kill or injure at least 28 host species and has been recovered from an additional 30 plant species. A great deal more information about the etiology of this pathogen, including requirements for infection and means of spread, is now available. This information strongly suggests that the southwestern corner, coastal areas, and Willamette Valley of Oregon are all at high risk for establishment of this pathogen.

RISK RATING DETAILS
Establishment Potential Is HIGH

Justification:

In Oregon, the natural ranges of the known oak, tan oak, and coast redwood tree hosts are limited mainly to the southwestern corner of the state and the southern Willamette Valley. Populations of wild rhododendrons, Pacific madrone, and manzanita can be found scattered throughout the state. The natural range of evergreen huckleberry and Douglas fir extends up the Oregon coastline into Washington. Populations are also found in the Cascade Mountain Range and, in the case of Douglas fir, elsewhere in Oregon. Other hosts are grown as landscape trees throughout the state. Thus, potential hosts are available throughout Oregon. Currently, natural spread of the pathogen appears to be limited to the coastal environments, or "fog belt", in California. Laboratory results indicate that the pathogen has a high moisture requirement for sporulation and infection. Observations in the field show this pathogen is most active in the winter and spring. This suggests possible environmental limitations to natural spread. Similar climatic conditions occur along Oregon's coastline and in the Willamette Valley. However, recent reports of the pathogen in Sweden, Spain, and other countries in Europe suggest the pathogen may have fewer environmental limitations than previously believed. Also, the pathogen can reportedly survive on infected plants grown in nurseries in hotter, drier areas such as Stanislaus County, California. This suggests that microclimatic conditions such as those found in nurseries may be sufficient for pathogen survival and spread. In addition,

preliminary data from Oregon State University and USDA-ARS suggest *P. ramorum* can survive in and spread from infested potting media to infect susceptible host plants. Movement of *P. ramorum* on infected nursery stock has been demonstrated in California, Oregon, Washington, British Columbia, and in Europe.

Economic Impact Potential Is HIGH

Justification:

This pathogen is capable of killing healthy mature oak and tan oak trees, wild rhododendrons, evergreen huckleberries, and *Viburnum* species. It can kill seedlings of Pacific madrone and coast redwood, while causing leaf spots and/or blights and tip dieback on mature plants. It also causes tip dieback on Douglas fir, thus affecting seedling establishment and plant growth. It causes disfiguring leaf spots on other host species, including big leaf maple and bay laurel, rendering the plants unmarketable. As the host list continues to grow, the economic impact becomes even more significant. Oaks are a commercial hardwood species and a nursery crop in Oregon. Tree mortality and resulting fuel loading in urban and forested areas would add significantly to fire prevention costs. Hazard tree removal costs and property value losses could also be significant. Douglas fir is the predominant timber species in Oregon and is also a critical component of the Christmas tree industry. Ability to re-establish harvested stands could be adversely affected. Plant growth may also be affected, rendering some trees unharvestable. *Rhododendron* species, particularly florist azaleas, are a significant component of Oregon's nursery industry. *Vaccinium ovatum* is a nursery and floriculture crop and an important secondary forest product. Blueberries, also in the genus *Vaccinium*, are grown as a fruit crop in Oregon. Other host species are harvested for secondary forest products or are grown as nursery stock in Oregon.

Environmental Impact Potential Is HIGH

Justification:

Tan oaks, oak species, rhododendrons, Pacific madrone, manzanita, Douglas fir, and evergreen huckleberry play important ecological roles in forests and woodlands as food and habitat for wildlife, and as soil cover in watersheds. The tan oaks, coast redwoods, Douglas fir, and oaks are significant riparian species, particularly in southwestern Oregon. Loss of these species could have an impact on fish habitats such as those of endangered wild salmon populations. The evergreen huckleberry is an important food and habitat source for wildlife. The loss of oak species, tan oaks, and evergreen huckleberry would also reduce biodiversity in these ecosystems. Urban environments may also be adversely affected as oaks are the predominant tree species planted along streets and other travel corridors. Several hosts, such as rhododendrons and viburnums, are commonly planted into landscape situations in and around homes and in state and city parks.

HOSTS

Phytophthora ramorum has been confirmed as naturally infecting the following hosts: *Acer macrophyllum* (big leaf maple), *Aesculus californica* (California buckeye), *Arbutus menziesii* (Pacific madrone), *Arctostaphylos manzanita* (manzanita), *Camellia* japonica (Japanese camellia), *C. sasanqua* (sasanqua camellia), *Hamamelis virginiana* (witch hazel),

Heteromeles arbutifolia (toyon), *Lithocarpus densiflorus* (tan oak), *Lonicera hispidula* (California honeysuckle), *Pieris formosa* (Himalaya pieris), *P. formosa x japonica* (pieris 'Forest Flame'), *P. floribunda x japonica* (pieris 'Brouwer's Beauty'), *P. japonica* (Japanese pieris), *Pseudotsuga menziesii* (Douglas fir), *Quercus agrifolia* (coast live oak), *Q. chrysolepsis* (canyon live oak), *Q. kelloggii* (California black oak), *Q. parvula var. shrevei* (Shreve's oak), *Rhamnus californica* (California coffeeberry), *Rhododendron* species (rhododendron and azalea), *Sequoia sempervirens* (coast redwood), *Trientalis latifolia* (Western starflower), *Umbellularia californica* (California bay laurel or Oregon myrtle), *Vaccinium ovatum* (evergreen huckleberry), *Viburnum x bodnantense* (bodnant viburnum), *V. plicatum* var. *tomentosum* (doublefile viburnum),and *V. tinus* (laurustinus). The pathogen has also been isolated from *Abies grandis, Aesculus hippocastanum*, *Arbutus unedo, Camellia reticulata, C. williamsii, Castanea sativa, Corylus cornuta, Fagus sylvatica, Kalmia latifolia, Leucothoe fontanesiana, Pieris formosa* var. *forrestii, P. formosa* var. *forrestii x P. japonica, Pittosporum undulatum*, *Quercus cerris, Q. falcata, Q. ilex, Q. rubra*, *Rhamnus purshiana, Rubus spectabilis, Syringa vulgaris, Taxus baccata, Toxicodendron diversiloba, Vaccinium vitis-idaea, Viburnum davidii, V. farreri, V. lantana, V. opulus, Viburnum x burkwoodi, Viburnum x carlcephalum x V. utile,* and *Viburnum x pragnense*, although Koch's Postulates needs to be completed on these "associated" hosts (USDA, January 2004 and United Kingdom Defra, February 2004). The complete host range of this pathogen remains to be determined.

GEOGRAPHICAL DISTRIBUTION

California: *Phytophthora ramorum* is currently found in 12 counties (Alameda, Contra Costa, Humboldt, Marin, Mendocino, Monterey, Napa, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma) of northern California.

Oregon: *P. ramorum* has been reported infecting 60 forested acres in Curry County, where an eradication effort is underway. In 2003, it was also detected on infested nursery stock in six nurseries. These nursery infestations have since been eradicated.

Europe: The pathogen has been reported in nursery and landscape situations Germany, The Netherlands, the United Kingdom, France, Poland, Italy, Spain, Belgium, and Sweden.

BIOLOGY

Phytophthora ramorum is a recently described species, genetically similar to *P. lateralis* (the cause of Port Orford cedar root rot) and *P. hibernalis* (the cause of brown rot of citrus). It is a cool temperature organism, with optimum growth at 20^{o}C. Numerous deciduous sporangia are produced *in vitro* and *in vivo*. Production of thick-walled chlamydospores is prolific *in vitro* and *in vivo*. These spores are desiccation-resistant, but have a limited tolerance for high temperatures. Sexual oospores have not been observed in the North American population. However, the formation of oospores has been induced *in vivo* by crossing North American isolates with European isolates (Werres et al, Hansen et al 2003). Symptoms caused by the pathogen are host-dependent. On oaks, tanoak and *Viburnum* species, the pathogen typically attacks phloem tissues, but commonly extends into the outer portion of the xylem. Infected phloem tissue is discolored while infected xylem tissues typically exhibit a dark, often streaky discoloration. A dark brown to black line is usually evident at the margins of the infected areas in both xylem and phloem. On some hosts, such as Douglas fir and rhododendron, the pathogen may infect and cause dark purple to black stem cankers on small branches and twigs leading to dieback of branch leaders. On other hosts, such as big leaf maple, the pathogen causes dark

purple to black leaf spots. These host species are generally infected through natural openings in the leaves (e.g., stomata). These foliar hosts, in particular California bay laurel, are believed to play a key role in the spread of *P. ramorum* in California. To date, the pathogen has not been isolated from below ground tissues of naturally infected hosts. However, root infection of susceptible host plants from infested potting media has been demonstrated in the laboratory (J. Parke, OSU, and R. Linderman, USDA-ARS, *personal communication*). It has been recovered from infected host materials, rain-splash, stream water, and soil.

PEST SIGNIFICANCE

Economic Impact: *Phytophthora ramorum* infects and kills or injures at least 28 plant species (see Hosts). It has been recovered from an additional 30 "associated" host species. The severity of the infection is host dependent, with some hosts killed outright (e.g., tan oak). Once infected, these hosts are more susceptible to secondary invaders such as wood-rotting fungi that often render the dead wood unusable. On other hosts (e.g., coast redwood) , *P. ramorum* is known to kill only the immature seedlings while causing tip dieback on mature plants. On still other hosts (e.g., California bay laurel), the pathogen causes unsightly leaf spots that can serve as a source of inoculum for other, more susceptible host species. The potential economic impact of this pest is described below for the major agricultural commodity groups and other industries in Oregon. Other groups and/or industries that may be affected directly or indirectly by *P. ramorum* are beyond the scope of this PRA.

Of the 28 currently recognized host species for *P. ramorum*, at least 27 are grown as nursery stock in Oregon. At least 20 nurseries are involved in the wholesale production and/or commercial sale of container grown, balled and burlapped, and/or bare root oak nursery stock. In contrast, literally thousands of nurseries are involved in the wholesale and/or commercial production of *Rhododendron* nursery stock. Most of these nurseries are found in the Willamette Valley. Nurseries would likely have to resort to additional fungicide sprays to protect their host nursery stock from *P. ramorum*, thus increasing their production costs. Nurseries would also be required to absorb the costs of meeting specific phytosanitary standards. The nursery industry is the top agricultural commodity in Oregon. In 2001, the gross sales of all floriculture, container grown, balled and burlapped, and bare root nursery stock was over $769 million.

Pseudotsuga menziesii is a key component of the timber industry in Oregon. It is the primary tree harvested for timber on public, private, and tribal lands, accounting for more than 1.6 billion board feet of the 2.28 billion board feet harvested in Western Oregon alone. The timber industry would be required to meet specific phytosanitary standards for the harvesting of trees, thus increasing their production costs. The timber industry may also encounter problems re-planting harvested sites, as *P. ramorum* is known to attack the apical leader on young seedlings. *Pseudotsuga menziesii* is also important to the Christmas tree industry; approximately 60% of all Christmas trees grown statewide are *P. menziesii*. The Christmas tree industry would experience similar problems to the timber industry. In addition, Christmas tree plantations may have to meet additional phytosanitary standards prior to harvest. Oregon is the top Christmas tree producer in the U.S. The Christmas tree industry is one of the top 10 agricultural commodities in Oregon, generating $149 million in 2001.

On *Vaccinium ovatum*, *P. ramorum* causes a severe dieback that can kill the plants. *Vaccinium* spp. are important nursery crops, contributing to the $769 million in gross sales for this industry. Huckleberries are an important secondary forest product in the Pacific Northwest and are of particular importance to our Native American peoples. The wholesale price for one

pound of huckleberries varied from $2.98 to $2.19 in 1995 and 1996, respectively, while the retail price varied from $7.61 to $12.83. The exact volume of huckleberries harvested varies from year to year. The blueberry (*V. corymbosum*) industry contributed nearly $15.8 million to the state's economy in 2001 and continues to grow with the expanding Japanese and California markets.

Several host species are also popular landscape plants in Oregon. Certain hosts can increase a property's value by several thousand dollars. For example, in southwestern Oregon, mature black oak trees may increase a property's value by $5,000 - 30,000 (survey of local realtors and property appraisers). The cost for removal of a single dead tree from a homeowner's property could run as high as $3,000 (survey of tree care professionals). A small, but steadily growing hardwood timber products industry exists in Oregon. The stumpage value of oak timber averages $156 per 1,000 bd ft in southwestern Oregon. This wood is used mainly for pallets, dunnage, and other rough-cut timber products (M. Dykzeul, Oregon Forest Industries Council, 2001, pers. comm.). If the oaks and possibly other species in the deciduous forests of the eastern U.S. prove susceptible to SOD, the potential threat to commercial timber production in the United States is in excess of $30 billion. The presence of dead tanoaks and oak species in southwestern Oregon would also be expected to increase the costs of fire protection and prevention by several millions of dollars (A. Kanaskie, Oregon Dept. of Forestry, 2001, pers. comm.).

Environmental Impact: The potential environmental impact of *P. ramorum* on Oregon forests and other ecosystems is described below for the known host species most severely affected by this pathogen. The potential environmental impact of *P. ramorum* on species that are not known to occur naturally in Oregon (e.g., toyon) are not considered in this section.

Quercus spp. are considered the most important and most widespread of the hardwood trees in the North Temperate Zone, with about 300 species. Oaks are widespread across North America and Eurasia, extending south in tropical mountains to Cuba, Colombia, northern Africa, and Indonesia. The United States has about 58 oak species of tree size and about 10 additional species classified as shrubs. Twenty of the native tree species are considered important in management of forest stands.

In Oregon, oak savanna covers over 200,000 acres in the Willamette Valley alone. The predominant species is the Garry oak (*Q. garryana*). California black oak, coastal live oak, canyon live oak, and interior live oak (*Q. wislizeni*) are also frequently encountered native species. California black oak and tan oak are important components of the mixed hardwood-conifer forests of southwestern Oregon. California black oak covers 96,930 acres with a total timber volume of 247.4 million cubic feet (A. Kanaskie, 2001, Oregon Dept. of Forestry, pers. comm.). Tan oak covers 300,190 acres with a total timber volume of 596.3 million cubic feet (A. Kanaskie, 2001, Oregon Dept. of Forestry, pers. comm.). Tan oak in particular is a critical under-story species. Numerous oaks are also planted as ornamentals throughout the state, particularly along streets in urban landscapes. Oak savanna and oaks found in mixed forests yield important benefits, including water and watershed protection, grazing, wildlife food and habitat, fish habitat, recreation, and wood products.

Several of the remaining host species may be found growing throughout Oregon with the largest populations concentrated near the Coast and Cascades Mountain Ranges. Hosts like wild rhododendron, Pacific madrone, manzanita, and evergreen huckleberry are valuable understory shrubs or minor tree species that provide water and watershed protection, wildlife food and

habitat, and recreational benefits. They are the dominant under-story shrubs in several regions. Losing the wild *Vaccinium* species may have an even greater environmental impact than losing the other host species in terms of harm to wildlife (B. Newhouse, Native Plant Society of Oregon, 2001, pers. comm.).

Heavy losses of oaks, tanoaks, and other *P. ramorum* host species could result in significant ecological effects, including changes in forest composition, loss of wildlife food and habitat, loss of fish habitat, increased soil erosion, and a significant increase in fuel loads in populated urban-forest interfaces.

Control: California has recently granted a 24(c) (special local need) registration for Agri Fos, a phosphonate-based chemical. According to the 24(c) label, this fungicide may be applied as a bark spray or via trunk injection. Data from California show that the chemical is not fungicidal, but does inhibit pathogen growth. The pathogen is reportedly susceptible to high temperatures. *In vitro* cultures of *Phytophthora* sp. nov. died after being exposed to 55°C for 1 hour. In experiments with composting treatments, composting has effectively killed the pathogen if the compost pile is maintained at a temperature of 55°C for at least 2-weeks.

DETECTION AND IDENTIFICATION

Symptoms: In general, symptoms on host plants fall into the following categories: stem cankers and foliar blight. The symptoms caused on specific hosts are described in detail below.

Diseased tan oaks and oaks exhibit symptoms that include crown dieback or wilting, stem bark lesions or cankers, and tarry, reddish to dark brown exudations characteristic of a *Phytophthora* root and collar rot. The exudations do not always develop on tan oak, especially on smaller diameter branches. The cankers are typically found on the lower trunk, within 3 to 15 ft of the soil line, sometimes extending all the way to the soil line. Branch cankers, especially on tan oak, also occur. These cankers have been observed as high as 60 ft up in the canopy. Infected hosts often appear to die suddenly, with crowns turning from apparently healthy green to yellow-green to brown within a few weeks.

Other agents typically associated with *P. ramorum*-infected coast live oaks and tan oaks include the sapwood decay fungus *Hypoxylon thourarsianum*, two species of ambrosia beetles (*Monarthrum scutellare* and *M. dentiger*), and the western oak bark beetle (*Pseudopityophthorus pubipennis*).

Other *Phytophthora* species. associated with oaks on the West Coast include *P. cinnamomi* (trunk canker, root rot), *P. citricola* (trunk canker), *P. cactorum* (bleeding canker, trunk canker) and the newly described *P. nemorosa* (bleeding stem cankers). *Phytophthora cinnamomi*, in particular, is associated with oaks in urban landscape situations. Other *Phytophthora* species, some not yet identified, are associated with oak decline in southern Europe and with oak forests of northeast France.

The symptoms observed on *Rhododendron* species are typical of a *Phytophthora* foliar blight. Leaf spots are irregular and necrotic and usually occur on the leaf tip. Spots could be easily confused with leaf scorch, chemical damage, or other abiotic injuries. Leaf petioles may also turn a black color as infection spreads. Branch cankers are typically black, but not necessarily sunken. If left unchecked, the stem canker can spread into the main stem of the plant eventually killing it. The leaf spot symptom is more prevalent than the canker symptom on rhododendrons subjected to a regular fungicide regimen (D. Rizzo, University of California,

Davis, 2001, pers. comm.). Several other *Phytophthora* spp. cause a similar leaf blight in Oregon: *P. cactorum*, *P. citricola*, *P. parasitica, P. syringae*, and *P. hevea*.

Phytophthora ramorum causes a dieback symptom on infected evergreen huckleberries similar to the symptoms produced on rhododendrons. Stem infections can kill the canes all the way back to the soil line. This pathogen also causes a rarely-seen leaf spot symptom on evergreen huckleberry. Leaf margins turn a dark purple to black color with the discoloration eventually spreading to cover the whole leaf. In general, however, the leaves fall off shortly after becoming infected. *Phytophthora cinnamomi* has been reported causing a root rot on *V. corymbosum* (blueberry) in Oregon.

Morphology: Colony characteristics and gametangial morphology have been described by Werres et al.

Testing Methods for Identification: The pathogen can be isolated from bark lesions, leaf spots, or stem cankers by plating onto a selective medium. Samples of inner bark (phloem) tissue from outer edges of necrotic lesions may be washed in running water and plated directly onto a selective medium for incubation at 20^{o}C (D. Rizzo, University of California, Davis, 2000, pers. comm.). It has also been isolated from soil, rain-splash, and stream water from around symptomatic plants by using pears, and rhododendron or viburnum leaves as baits. *Phytophthora ramorum*-specific primers and probes for use with the polymerase chain reaction (PCR)have been developed in multiple labs.

MEANS OF MOVEMENT AND DISPERSAL

Phytophthora ramorum has been isolated from infected nursery stock and other host plant materials, from soil, from rain-splash, and from stream water.

Long-distance spread of this pathogen on infected nursery stock has been demonstrated in Europe, California, Oregon, Washington, and British Columbia. In Europe, the pathogen is considered predominantly a nursery problem on *Rhododendron* and *Viburnum* species. All "first reports" of the pathogen in countries in the European Union (e.g., France and Spain) have been associated with nurseries and/or garden centers. However, the pathogen has been reported infecting rhododendrons in landscape plantings in at least three countries; The Netherlands, Germany, and the United Kingdom. Recently, The Netherlands and the United Kingdom have reported finding *P. ramorum*-infected trees including *Q. falcata* and *Q. rubra* (both native to North America) in established plantings.

The pathogen has been successfully isolated from a dead tree that was cut down 3-months prior to sampling and has been observed actively sporulating on infected rhododendron and bay laurel leaves placed in a moisture chamber. Researchers have demonstrated the movement of spores from green leaf litter in the soil into healthy , above-ground bay laurel leaves and from infested potting media into healthy rhododendron roots, stems, and leaves (J. Parke, OSU, pers. comm.). Researchers have also correlated periods of peak spore production with rain events, particularly in the spring. During the spring, *P. ramorum* can be baited out of soil collected from hiking trails and from hikers' shoes 40-60% of the time and 40-95% of the time, respectively. Spores can be recovered routinely from rain splash, soil, and green litter at this time with the greatest number of spores recovered towards the end of the rainy season. Spores have also been recovered from stream water flowing out of infested areas in California and Oregon, although the role of these spores in spread has yet to be determined.

Oospores and chlamydospores of other *Phytophthora* species are long-lived and capable of surviving in soil and dead host tissues under adverse conditions. Experimental results show that *P. ramorum* chlamydospores can survive desiccation *in vitro* and *in vivo* (D. Rizzo, University of California, Davis, 2000, pers. comm.). Survival requirements of the pathogen in bark used as mulch are currently under investigation. Preliminary results indicate the pathogen can survive for several weeks in different types of potting media (R. Linderman, USDA-ARS, pers. comm.). The pathogen has been recovered from wood and will actively sporulate on infected wood chips left in standing water (E. Hansen, Oregon State University, 2001, pers. comm.). Preliminary results suggest that composting infected green waste material will kill the pathogen provided the compost pile maintains a temperature of 55°C for a minimum of 2-weeks.

Currently, the intra- and interstate movement of nursery stock and other regulated commodities from infested areas in California and Oregon are regulated by an USDA interim regulation and state quarantines. However, movement of certain regulated and/or restricted articles from the quarantined area in California has continued. For example, the USDA has allowed the movement of more than 3,000 tons of tan oak wood chips with more than 24 tons of bark (a restricted article) still attached into uninfested areas in the states of Oregon and Washington.

For the past four years, a survey has been conducted in Oregon by the Oregon Departments of Agriculture and Forestry, the USDA Forest Service and Oregon State University with particular emphasis on the southwestern corner of the state. *Phytophthora ramorum* has been found infesting 60 acres of private and public forested land within an 11-mi^2 area in Curry County. Oregon is actively attempting to eradicate the pathogen in this area (Figure 1). All host plants within each infected site are cut, piled, and burned. The site is then monitored for at least two years for the presence of the pathogen. In 2001, when the eradication effort began, a total of 40 acres were infected. In 2002, the total number of new acres infected decreased to 8. In 2003, the total number of new acres infected increased slightly to 12. Natural spread of the pathogen appears to progress along the prevailing wind and rain weather patterns within the quarantine area. Very little *P. ramorum* has been recovered from these sites after treatment has occurred (1.1% of all samples tested). As of January 2004, of 2,422 plant samples collected within the sites, 36 were positive for *P. ramorum*; of 1,126 soil samples collected, three were positive. The majority of positive plant samples (94%) were from sprouts off of infected tan oak stumps. All sites with positive samples have been subsequently treated. In 2003, *P. ramorum* was detected for the first time on nursery stock in six Oregon nurseries. All infected nursery stock was destroyed by incineration and the nurseries subsequently inspected for *P. ramorum*. No *P. ramorum* was detected during these inspections. Delimitation surveys were also conducted around each nursery to determine if the pathogen had become established in the natural environment. The pathogen was not detected in the natural environment. This data indicate *P. ramorum* was successfully eradicated from the affected nurseries.

Figure 1. The burning of piles of host plant materials on a *Phytophthora ramorum* infection center in Curry County, OR (courtesy of F. Arnold, 2001).

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