Oak wilt: *Ceratocysis fagacearum*

Pest Risk Assessment

This risk assessment follows the format used by the Exotic Forest Pest Information System for North America. Guidelines are listed at http://spfnic.fs.fed.us/exfor/download.cfm.

IDENTITY
Name: *Ceratocystis fagacearum* (Bretz) Hunt
Taxonomic Position: Fungi: Ascomycetes: Ophiostomatales
Common Name: Oak wilt

RISK RATING SUMMARY
Relative Risk Rating: HIGH
Degree of Uncertainty: Very certain.
Uncertainty in this assessment results from: *Ceratocystis fagacearum* has been studied extensively since initially detected in the 1940's. Current molecular evidence suggests the pathogen was introduced to the United States from an unknown location.

RISK RATING DETAILS
Establishment Potential Is: HIGH
Justification: Based on molecular analyses, *C. fagacearum* is now believed to be a non-native pathogen that was introduced to the United States in the 1940's. The predominant oak species growing throughout western Oregon is the Oregon white oak. Although white oaks are reportedly less susceptible to the pathogen, they can serve as reservoirs of inoculum. Several insect vectors have been identified for this pathogen. Although not considered terribly efficient, these vectors are responsible for establishing new infection centers beyond the leading edge of infection.

Spread Potential is: MODERATE
Justification: The pathogen can sporulate on firewood that hasn't been treated properly and thus move through that avenue. Infections may be difficult to detect in Oregon white oaks because of the reported greater resistance to the pathogen in white oak species. Insect vectors can help this pathogen spread and become established in new areas.

Economic Impact Potential Is: MODERATE
Justification: Oak wilt kills red oaks and causes gradual decline and eventual death in white oaks. Oaks are a popular landscape tree within Oregon's urban boundaries. The European Union has quarantined oak logs and lumber harvested from infested states. Exporters must debark and fumigate logs prior to shipment to the European Union.

Environmental Impact Potential Is: HIGH
Justification: Oaks are considered critical habitat species in Oregon for numerous bird and mammalian species. The distributions of canyon live oak and California black oak are limited to counties in southwestern Oregon. Although more widespread, Oregon white oak is limited primarily to western Oregon.

HOST(S)
Quercus spp. and *Castanea* spp. Other hosts have been shown to be susceptible in laboratory experiments.

GEOGRAPHIC DISTRIBUTION

Ceratocystis fagacearum has been reported in the Eastern United States (Alabama, Arkansas, Iowa, Illinois, Indiana, Kansas, Kentucky, Louisiana, Maryland, Michigan, Minnesota, Missouri, Mississippi, Nebraska, New York, North Carolina, Ohio, Oklahoma, Pennsylvania, South Carolina, Tennessee, Texas, Virginia, Wisconsin, and West Virginia). There are also unconfirmed reports of *C. fagacearum* being detected in Spain, Poland, and the Netherlands.

BIOLOGY

Ceratocystis fagacearum is a vascular wilt pathogen. The fungus is confined to the outermost ring of the xylem. No species of oak is known to be immune to oak wilt, although red oaks (subgenus *Erythrobalanus*) are known to be highly susceptible with trees dying within a few weeks of infection whereas white oaks (subgenus *Lepidobalanus*) are more resistant with trees recovering from infection or dying over a period of several years. In diseased red oaks, spores can be passively transported to all parts of the tree via the transpiration stream. When a red oak dies, the fungus will grow out into the inner bark, producing a sporulating mat although high summer temperatures and competing fungi can inhibit mat production. Conidiophores are produced initially in the mats, followed by perithecia if fertilization with the opposite mating type occurs. Typically, mats only last about a year because of the activities of antagonistic fungi. The pathogen survives longer in the root system, especially if the infected tree has root grafts with neighboring trees. In diseased white oaks, distribution of the fungus in the current annual ring of the xylem is much more limited. If a white oak recovers from infection, the infected ring is buried under new xylem and is unlikely to become a source of inoculum for further infections.

The most important means of dispersal for oak wilt is via the transportation of spores through root grafts between adjacent trees. When one tree dies of oak wilt, neighboring trees use the dead tree's root system for water transpiration; this results in the movement of spores from dead tree to live one. In areas where large tracts of oaks are root grafted together, the disease can spread quite rapidly, as much as 7.5 m/yr in *Q. ellipsoidalis* stands to 16 m/yr in *Q. fusiformis* stands. About 95% of disease spread is attributed to root graft transmission.

Aerial spread occurs much less frequently. This occurs via the feeding activity of nitidulid beetles, which are attracted by the odor produced by the sporulating mats. When the beetles feed on the mats, fungal spores adhere to their bodies. When the beetle leaves the mat to feed on fresh wounds on healthy trees, the spores are transmitted. In parts of the southern US, *Pseudopityophthorus* beetles are also considered important vectors. New outbreaks in previously uninfected areas are generally associated with the activities of insect vectors.

PEST SIGNIFICANCE

Economic Impact: The native species *Quercus garryana* (Oregon white oak), *Quercus chrysolepsis* (canyon live oak), and *Quercus kelloggii* (California black oak) are used primarily for specialty timber products such as veneer, moulding, millwork, paneling, furniture, flooring, panels, pallets, fence posts, chips for landscaping, and fuel. Canyon live oak has been planted on steep, rocky, moving slopes to help stabilize the soil. Oregon white oak is an excellent host for the gourmet truffle *Tuber melanosporum* and the feasibility of managing Oregon white oak stands for truffle production is being investigated. The estimated timber inventory for Oregon white oak is 450 MMCF in western Oregon and northern California and for California black oak 131 MMCF in southwestern Oregon.

Species native to the eastern U.S., including *Quercus coccinea* (scarlet oak), *Q. pallustris* (pin oak), and *Q. rubra* (Northern red oak), are popular street trees in Oregon's urban areas. In

Eugene, pin oaks account for 4% of the trees planted on the University of Oregon campus, with Northern red oaks and scarlet oaks also having a significant presence. Studies about trees and residential property values have shown that property values for single family homes increase by an average of 7% when a mature tree is present either in the yard or as a nearby street tree. In high-income neighborhoods, the presence of a mature tree can increase the property value by 10-15%, while in low-income areas the increase may be even greater.

Quercus species are grown as nursery stock in Oregon, primarily as bare-root or as balled and burlapped trees. These segments of the nursery industry accounted for about $240 million in 2009.

A recent case study estimated the baseline economic damage from oak wilt in Anoka County, Minnesota. The metric of economic damage used was tree removal cost. Anoka County currently has about 5.92 million oak trees and about 885 active oak wilt infection centers. Haight et al estimated that over the next 10-years, the economic damage would be between $18-60 million to the county. Actual cost depended upon the rate of disease spread and the likelihood of landowners to remove dead trees.

The European Union has established a quarantine against oak wilt, requiring logs imported from the United States by debarked and treated with a fumigant prior to shipment.

Environmental Impact: Oregon white oak is one of only four deciduous oaks native to the West Coast. It can be found growing in variety of habitats from Vancouver Island, British Columbia, to southern California. It is a persistent climax or sub-climax species on dry sites or under regimes of periodic fire. These trees are considered very important for wildlife, providing food and habitat for many species, particularly various bird species.

Canyon live oak is an evergreen oak found in the southern Coast and Cascade ranges in Oregon. It can also be found in California, extending down into Baja California, Mexico, with scattered populations in Nevada and Arizona. It is often the dominant tree on steep canyon walls and is often associated with Douglas-fir, tanoak, and Pacific madrone in mixed evergreen forests. Canyon live oaks provide food and habitat for a wide variety of wildlife, including several bird species, black bears, and mule deer. It is also popularly used to stabilize soils on steep slopes.

California black oak is the most abundant oak on the West Coast and the most similar to eastern red oaks. Its native range extends from Eugene, Oregon, to the Baja California, Mexico. It is another climax or sub-climax species that depends upon periodic fire for regeneration of stands. It, too, is an important food source for birds, rodents, deer, and bear, and provides habitat for cavity-nesting animals.

Non-native red oaks are popular urban shade trees in Oregon cities. Scarlet oak, pin oak, and Northern red oak are the most popular, particularly throughout the Willamette Valley. All three trees are native to the eastern and central United States.

Control: There is no cure for an oak tree once it becomes infected with oak wilt, although therapeutic intravascular injections with propiconazole have been shown to generally prevent further disease development in two white oak species (*Q. alba* and *Q. macrocarpa*) within 5-years. However, therapeutic injections of already infected red oaks generally are unsuccessful. Prophylactic intravascular injections of oaks prior to disease spread have improved survival rates for live oaks in Texas and have successfully prevented disease development in two red oak species (*Q. rubra* and *Q. ellipsoidalis*) for two growing seasons following injection. Research has shown

that the fungicide does not eradicate the fungus from the roots, but simply prevents the disease from developing. Once the fungicide breaks down, the disease will manifest itself.

In general, the disease oak wilt is managed through an integrated approach that includes removal of inoculum sources, disrupting root graft transmission, and preventing insect vector transmission. The immediate removal and disposal of infected trees, particularly red oaks, is strongly encouraged. Acceptable methods include burning, chipping, or any other process that encourages rapid drying of the wood or colonization by competing fungi. Care must be taken with infected oak trees harvested for firewood as fungal mats can still form even on short lengths of wood. Firewood should be covered with clear plastic and the edges of the plastic buried to prevent insects from visiting the wood. To prevent vector transmission, avoid pruning or wounding healthy oaks in the spring when the insect vectors are most active and the trees most susceptible to infection. If trees must be pruned, the wounds should be immediately painted to prevent the insect vectors access to the wood. The majority of spread is through root graft transmission. Thus, disruption of these root grafts is an integral part of disease management. Successful treatments result from digging a deep trench (48-60") between healthy and diseased trees; the trenches must be placed 15-30 yards out from the nearest diseased tree.

DETECTION AND IDENTIFICATION

Symptoms: Symptoms in red oaks are generally first observed in the spring. Leaves turn dull green or bronze, appear water-soaked, wilt, and then turn yellow or brown. Damage occurs from the tip and outer edges in towards the mid-rib and petiole, with a distinct line between the bronze and green tissues (Figure 1). Leaf symptoms quickly appear throughout the crown. Heavy defoliation accompanies the leaf wilting and discoloration. Leaf symptoms and defoliation typically occurs from the top of the tree down, although some branches may hold onto green leaves until autumn. The disease progresses very rapidly, with trees dying within 1- to 2-months after the onset of symptoms. Most trees die within 12-months. Fungal mats form on the boles of dead trees under the bark. The mats may crack the bark, giving off a fermenting odor that attracts insects. Typical, vascular discoloration of the annual ring is observed only within the lower bole and exposed roots; even then this symptom may not be obvious.

In white oaks, disease symptoms are much more variable, although leaf symptoms are similar (Figure 1). In bur oaks (*Q. macrocarpa*), symptoms are generally identical to those in red oaks and trees may die within a year of infection. Typically, however, white oaks die much more slowly; one or two branches may die a year until eventually the whole tree declines. Some white oaks appear more resistant and seem to recover from the disease. These trees serve as symptomless reservoirs for the pathogen. Because they die more slowly, white oaks frequently have discolored infected annual rings (Figure 2). Fungal mats are rarely formed on white oaks.

Foliar symptoms in evergreen, or live, oaks are different from those seen in the deciduous red and white oaks. Diseased live oaks typically develop yellow veins that eventually turn brown, a symptom called veinal necrosis (Figure 1). Like red oaks, defoliation and tree death may be rapid.

Morphology: On malt agar, fungal cultures are greyish with a sweet fruity smell. Endoconidiophores and endospores are produced in culture, the latter with an angular growth habit (Figure 3). Perithecia appear after 7-10 days in culture, are flask-shaped and black with a spheroidal base, and 240-380 υm in diameter with an erect beak 250-450 υm long. Ascospores are hyaline, one-celled, elliptical, 2-3 x 5-10 υm, exuded in a sticky creamy-white mass.

Testing Methods for Identification: The standard protocol for confirming the presence of *C. fagacearum* is isolation in the laboratory. Isolation from red oaks is easier than from white oaks.

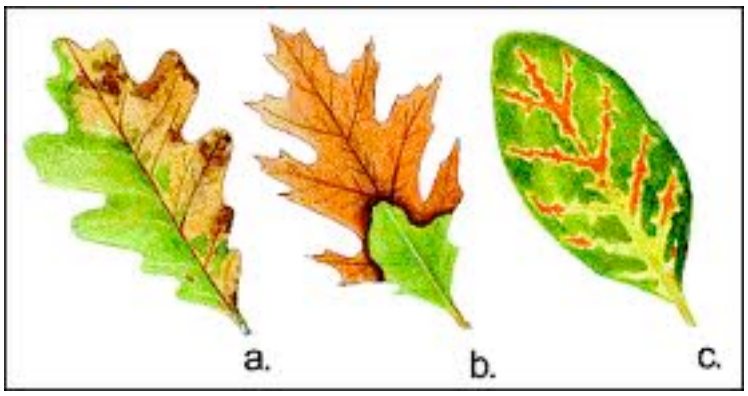

Figure 1. Foliar symptoms of oak wilt on (a) white oak, (b) red oak, and (c) live oak (Image from Google).

Figure 2. Vascular discoloration of the annual ring in an oak tree caused by oak wilt (Image by Canadian Food Inspection Agency).

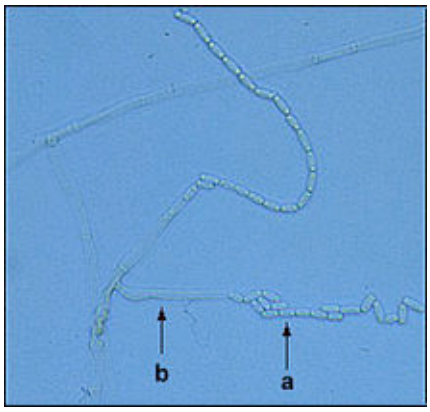

Figure 3. Endoconidia (a) and endoconidiophore (b) of *Ceratocystis fagacearum* in culture (Image by J. Martinez, from Wikipedia).

Small pieces of wood are cut from the outer two or three annual rings. Surface-sterilize the wood chips by dipping them in 70% alcohol and flaming. Then push the chips down into 2% malt agar or acidified potato dextrose agar (aPDA). Incubate plates in the light or dark for 8-10 days at 20-25°C and then examine. The fungus is easily identified in culture because of the endoconidiophore and endoconidia morphology (Figure 3) as well as the sweet odor produced by the fungus on aPDA. It is possible to detect *C. fagacearum* in artificially inoculated wood with a nested PCR technique that uses the universal primers ITS1 and ITS4 and species-specific primers. ITS nrDNA and LSU nrDNA sequences have been deposited in GenBank.

MEANS OF MOVEMENT AND DISPERSAL

This pathogen normally spreads by root grafting and more rarely above ground by insect transmission. Although the disease typically is reported from forest trees, spread via infected nursery stock is theoretically possible although likely only on white oaks. Oak wood carrying sporulating mats is considered the primary pathway for long distance dispersal, with non-debarked wood presenting the highest risk.

BIBLIOGRAPHY

Appel, D.N., and T. Kurdyla. 1992. Intravascular injection with propiconazole in live oak for oak wilt control. Plant Disease 76(1): 1120-1124.

Appel, D.N., R.S. Cameron, A.D. Wilson, and J.D. Johnson. 2008. How to identify and manage oak wilt in Texas. How-To SR-1, USDA Forest Service, Southern Research Station, 2 pp.

Blaedow, R.A., B. Barber, and J. Juzwik. 2010. Propiconazole distribution and effects on *Ceratocystis fagacearum* survivals in roots of treated red oaks. Phytopathology 100(10): 979-985.

Burns, R.M. and B.H. Honkala (Tech. Coords.). 1990. Silvics of North America: 2. Hardwoods. Agriculture Handbook 654, USDA Forest Service, Washington, DC, vol. 2, 877 pp.

CABI and EPPO. 1997. Data Sheets on Quarantine Pests: *Ceratocystis fagacearum* and its vectors. In: Quarantine Pests for Europe (2nd Ed.). 1,425 pp.

Chase, J. 2008. Scarlet Oak – *Quercus coccinea*, In: Forests for Oregon: Summer 2008. Oregon Dept. of Forestry, Salem, OR, pp. 16-17.
Leamaster, K.K. 2010. Oregon Agripedia: 2010 Edition. Oregon Department of Agriculture, Salem, OR. 244 pp.

EPPO Standards. 2000. Diagnostic protocols for regulated pests: *Ceratocystis fagacearum*. PM 7/1(1), European and Mediterranean Plant Protection Organization, 7 pp.

Haight, R.G., F.R. Homans, T. Horie, S.V. Mehta, D.J. Smith, and R.C. Venette. 2011. Assessing the cost of an invasive forest pathogen: A case study with oak wilt. Environmental Management 47(3): 506-517.

Jensen-Tracy, S., T. Harrington, C. Logue, S. Kenaley, and G. Hudler. First report of the oak wilt fungus, *Ceratocystis fagacearum*, in New York state. Plant Disease 93(4): 428.

Juzwik, J., D.N. Appel, W.L. MacDonald, and S. Burks. 2011. Challenges and successes with managing oak wilt in the United States. Plant Disease 95(8): 888-900. doi: 10.1094/PDIS-12-10-0944.

Juzwik, J., and J.M. Meyer. 1997. Colonization of oak wilt fungal mats by *Ophiostoma piceae* during spring in Minnesota. Plant Disease 81(4): 410-414.

Juzwik, J., J.M. Meyer, and K.R. Cease. 1998. Acquisition of *Ophiostoma quercus* and *Ceratocystis fagacearum* by nitidulids from *O. quercus*-colonized oak wilt mats. Plant Disease 82(2): 239-243.

Niemiec, S.S., G.R. Ahrens, S. Willits, and D.E. Hibbs. 1995. Hardwoods of the Pacific Northwest. Research Contribution 8, Oregon State University Forest Research Laboratory, Corvallis, OR. 125 pp.

Osterbauer, N.K., and D.W. French. 1992. Propiconazole as a treatment for oak wilt in *Quercus rubra* and *Q. ellipsoidalis*. Journal of Arboriculture 18(5): 221-226.

Rexrode, C.O., and D. Brown. 1983. Oak wilt. Forest Insect and Disease Leaflet 29, USDA Forest Service, 5 pp.

Wilson, A.D., and L.B. Forse. 1997. Sensitivity of Texas strains of *Ceratocystis fagacearum* to triazole fungicides. Mycologia 89(3): 468-480.

Wolf, K.L. 2007. City trees and property values. Arborist News 16 (4): 34-39.

Prepared by: Nancy K. Osterbauer, Ph.D., Plant Health Program Supervisor
Affiliation: Oregon Department of Agriculture, 635 Capitol St. NE, Salem, OR 97301
Date: November 4, 2011