United States Department of Agriculture
Animal and Plant Health Inspection Service
Plant Protection and Quarantine

Risk Analysis for

Phytophthora ramorum Werres, de Cock & In't Veld,

Causal Agent of Phytophthora Canker (Sudden Oak Death),

Ramorum Leaf Blight, and Ramorum Dieback

Gary L. Cave, Ph.D., Entomologist
Betsy Randall-Schadel, Ph.D., Plant Pathologist
Scott C. Redlin, Ph.D., Plant Pathologist

United States Department of Agriculture
Animal and Plant Health Inspection Service
Plant Protection and Quarantine
Center for Plant Health Science and Technology
Plant Epidemiology and Risk Analysis Laboratory
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Executive Summary

This pest risk analysis was conducted by the United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Center for Plant Health Science and Technology, Plant Epidemiology and Risk Analysis Laboratory to assess the risk of the importation and domestic spread of *Phytophthora ramorum* Werres, de Cock, & In't Veld. This pathogen is the subject of USDA Emergency Regulations due to its threat to agricultural and natural ecosystems of the United States. The analysis focused on 1) the risks associated with the importation of plants (including plants in APHIS-approved growing media and bare-root plants) and plant products (wood, lumber, chips, bark and other wood products, and greenery) that are hosts of *P. ramorum;* 2) the risks associated with the domestic movement of the pathogen through plant products, soil, other growing media, compost and water; and 3) mitigation measures to prevent the movement and spread of *P. ramorum* to non-infested areas in the United States.

Diseases caused by an unknown species of *Phytophthora* were first observed in Europe on nursery stock in 1993 and in California forests on *Quercus* spp. and *Lithocarpus californica* in 1995, but the pathogen, *P. ramorum*, was not formally described until 2001. Since initial reports and detections, *P. ramorum* has expanded its geographic distribution in California and Oregon and has been detected in an increasing number of nurseries in Europe and North America. The pathogen has been detected with increasing frequency both on new hosts and in nurseries outside of quarantined areas.

Several biological factors affect the risk of introduction and establishment of *P. ramorum* including the large host range, a large variation in symptoms, the production of multiple spore states, and factors inducing and breaking latency and dormancy. The large host range is mirrored by complexity of disease symptoms. Hosts can exhibit the symptoms of one or more of three different diseases.

The overall risk presented by *P. ramorum* is High due to the number of pathways associated with, and the biological uncertainties of the pathogen, *e.g.*, long term viability of infective propagules, detection of the propagules, lack of definitive host range, the sensitivity of detection of infected plants by visual inspection, and means of natural movement. Research is needed on: (1) factors inducing and breaking dormancy in chlamydospores, which is needed to develop effective detection protocols and mitigation measures; (2) increased sensitivity and specificity of detection techniques; (3) temperature requirements for survival of propagules in various sources, *e.g.*, soil, wood; (4) risk of moving the pathogen in various species and hybrids of plants for planting, Christmas trees (cut and uncut), cut flowers and cut foliage; (5) screening for more potential hosts including products and propagative material of vegetable, fruit and nut crops; (6) natural dispersal especially animal and aerial dispersal; and (7) origin of *P. ramorum* is not known.

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I. INITIATING EVENT: PROPOSED ACTION

This pest risk analysis (PRA) was conducted by the United States Department of Agriculture, Animal and Plant Health Inspection Service, Plant Protection and Quarantine, Center for Plant Health Science and Technology, Plant Epidemiology and Risk Analysis Laboratory (USDA, APHIS, PPQ, CPHST, PERAL) to assess the risk of the importation and domestic spread of *Phytophthora ramorum* Werres, de Cock, & In't Veld. This pathogen is the subject of USDA Emergency Regulations due to its threat to agricultural and natural ecosystems of the United States. This document will focus on 1) the risks associated with the importation of approved plants (including plants in APHIS-approved growing media and bare-root plants) and plant products (wood, lumber, chips, bark and other wood products, and greenery) that are hosts of *P. ramorum;* 2) the risks associated with the domestic movement of the pathogen through plants, plant products, soil, other growing media, compost and water; and 3) mitigation measures to prevent the movement and spread of *P. ramorum* to non-infested areas in the United States.

The Authority for APHIS to regulate plant pests and plant products is derived from the Plant Protection Act of 2000 (7 USC §7701 *et seq*.), for plant imports, the Nursery Stock, Plants, Roots, Bulbs, Seed and Other Plant Products subpart of the Code of Federal Regulations (7 CFR §319.37), and for regulating domestic interstate movement of items at risk for moving *P. ramorum*, PHYTOPTHTHORA RAMORUM (7CFR §301.92) . The risk assessment methodology and rating criteria (APHIS, 2000) and the use of biological and phytosanitary terms is consistent with relevant international standards published by the International Plant Protection Congress (IPPC).

This pest risk analysis is prepared in response to a need to promulgate regulations addressing the domestic and international movement of *P. ramorum*, its recognized hosts, and products associated with those hosts, including soil and compost. The domestic movement of *P. ramorum* is currently regulated under an Interim Rule, "Domestic Quarantine Notices *Phytophthora Ramorum"* 7 CFR § 301.92, and an Agriculture Department Emergency Federal Order Restricting Movement of Nursery Stock from California, Oregon, and Washington Nurseries (Dec. 21, 2004). USDA implemented emergency measures to regulate international movement of regulated articles from the European Union which mirrored the federal domestic regulations and were effective November 1, 2002. Changes in Federal domestic emergency measures were applied to movement from the EU (March 26, 2003; January 30, 2004 and April 15, 2004).

II. GLOSSARY

Baiting – A method of recovering fungi form aquatic and soil/potting media by using various types of organic substrates. Classic baiting techniques for species of *Phytophthora* (Erwin and Ribeiro, 1996) using pears and leaves of hosts are used for *P. ramorum* (APHIS, 2004).

Chlamydospore – Spore, usually globose but occasionally ovoid, that is delimited from the mycelium by a septum and may be terminal (at the end of the hyphae) or intercalary (formed in the middle of a hyphal strand) with a thickened wall. " …survives for a long time in soil " (Erwin and Ribeiro, 1996).

Disease Cycle – The sequence of events involved in disease development, including the stages of development of the pathogen and the effect of the disease on the host; the chain of events that occurs between the time of infection and the final expression of disease (Shurtleff and Averre, 1997).

Hosts – A living organism (*e.g.,* a plant) harboring or invaded by a parasite and from which is the parasite obtains part or all of its nourishment (Shurtleff and Averre, 1997).

Regulated Hosts – Host plants that are naturally infected and for which Koch's postulates have been completed, documented, reviewed and accepted. Some are regulated in part (such as redwood and Douglas fir) and some are regulated in their entirety (such as tanoak and western starflower) (APHIS, 2005b).

Associated Hosts – Host plants that are reported found naturally infected and from which *P. ramorum* has been cultured and/or detected using PCR (polymerase chain reaction). For each of these, traditional Koch's postulates have not yet been completed or documented and reviewed. These reports much be documented and reviewed by PPQ before they will be listed (APHIS, 2005b).

Experimental Hosts – Host plants that indicating susceptibility to infection by *P. ramorum* in experiments.

Host range – The complete range of plants that may be attached by a given pathogen (Shurtleff and Averre, 1997).

Heterothallic – Self-sterility; a sexual condition in which an individual produces only one kind of gamete: used chiefly in reference to fungi and algae (Shurtleff and Averre, 1997).

Hypha(e) – The basic vegetative unit of structure and function of most fungi; a largely microscopic tubular filament that increases in length by growth at its tip. New hyphae arise as lateral branches. Some can become specialized for given functions including spore producing, penetrating host tissues, etc. (Erwin and Ribeiro, 1996).

Koch's Postulates – Four rules, proposed by Robert Koch, to be followed to prove the pathogenicity of a microorganism. The rules below work well for most fungal, protistal, bacterial and related organisms. A modification is used for Viruses (Shurtleff and Averre, 1997)

Rule 1. Organism is consistently associated with a disease syndrome.

Rule 2. Organism is isolated and grown in pure culture.

Rule 3. Organism is used to inoculate a healthy host of the same species and the same disease syndrome noted in rule 1 is observed.

Rule 4. Organism is re-isolated from the inoculated plant and it has the same characteristics as the initial isolate.

Latent infection – Infection in a plant without visual symptoms (Shurtleff and Averre, 1997). See Latency.

Latency – Stage of an infectious disease, other than the incubation period, where no symptoms are expressed in the host (Shurtleff and Averre, 1997).

Life cycle – Cyclical progression of stages in the growth and development of an organism (plant, animal, or pathogen) that occur between the appearance and reappearance of the same stage of the organism (Shurtleff and Averre, 1997).

Mating type - Compatible strains, usually designated + and – or A and B, necessary for sexual reproduction in heterothallic fungi (Shurtleff and Averre, 1997).

Monocyclic - Having one cycle per growing season; no secondary infections (Shurtleff and Averre, 1997).

Mycelium – Tubular strands that make up the body of the fungal microorganism. In *Phytophthora*, mycelium is non septate, but plugs, often called false septa, can be seen in old mycelium (Erwin and Ribeiro, 1996).

Oomycete/Oomycota - A fungus-like chromistan that produces oospores. A water mold (Shurtleff and Averre, 1997).

Oospore – Thick-walled, resting spore in the oomycetes that develops from a fertilized oosphere or by parthenogenesis (Shurtleff and Averre, 1997).

Pest risk analysis – The process of evaluating biological or other scientific and economic evidence to determine whether a pest should be regulated and the strength of any phytosanitary measures to be taken against it (FAO, 2002).

Pest risk assessment – Determination of whether a pest is a quarantine pest and evaluation of its introduction potential (FAO, 2002).

Pest risk management – The decision-making process of reducing the risk of introduction of a quarantine pest (FAO, 2002).

Polycyclic – A disease of which many cycles occur in one growing season, resulting in many secondary infections (Shurtleff and Averre, 1997).

Propagule – Any part of an organism capable of initiating independent growth when separated from the parent body (Shurtleff and Averre, 1997). In the case of *P. ramorum*, progagules reported from nature are mycelium, sporangium, chlamydospores, and zoospores. Oospores have been produced in the laboratory.

Soil –The loose surface material of the earth in which plants grow, in most cases consisting of disintegrated rock with an admixture of organic material (NAPPO, 2004).

Sporulate, Sporulation – To form or produce spores (Shurtleff and Averre, 1997).

Sporangium/sporangia – Sac within which zoospores form, especially when water is cooled to about 10°C below ambient temperature. In solid substrates, sporangia usually germinate by germ tubes (Erwin and Ribeiro, 1996).

Zoospore – Spore that forms within the sporangium and exits through the terminal pore, has a tinsel and a whiplash flagellum, and is capable of swimming for several hours (Erwin and Ribeiro, 1996).

III. PEST DATA SHEET

A. IDENTITY

Name: *Phytophthora ramorum* Werres, de Cock, & In't Veld (2001)
Synonym: none
Taxonomic position: Chromista: Oomycota:Oomycetes: Pythiales:Pythiaceae: Phytophthora
Disease names: Sudden Oak Death, Phytophthora canker disease of oaks, Ramorum leaf blight, Ramorum twig blight or dieback

B. HOSTS

The host range (Table 1) for *Phytophthora ramorum* is broad and continues to expand. Currently, 31 plant species are designated as proven hosts and an additional 37 species as associated plants by USDA [Domestic Quarantine Notices *Phytophthora Ramorum* 7 CFR § 301.92; Agric. Dep't. Orders DA-2002-17 (Sept. 5, 2002), DA-2002-18 (Sept. 24, 2002), DA2003-1 (Jan. 28, 2003), DA-2003-2 (Feb. 6, 2003), DA-2003-7 (Mar. 11, 2003), DA-2004-03 (Jan. 8, 2004), DA-2004-15 (Apr. 29, 2004), DA-2004-19 (June 23, 2004), DA-2004-20 (June 23, 2004), and DA-2004-30 (Aug. 5, 2004); Agric. Dep't. Emergency Federal Order Restricting Movement of Nursery Stock from California, Oregon, and Washington Nurseries (Dec. 21, 2004); APHIS, 2005a, b)]. The difference between proven hosts and associated plants is the demonstration of Koch's Postulates. There are four steps comprising Koch's Postulates: 1) pathogen is consistently associated with a given symptom(s); 2) pathogen is isolated and grown in pure culture; 3) pathogen is used to inoculate a healthy host of the same species and the same disease symptom(s) noted in step 1 is observed; and 4) pathogen is re-isolated from the inoculated plant and it has the same characteristics as the initial isolate. "If all of the above steps…are followed and proved true, then the isolated pathogen is identified as the organism responsible for the disease" (Agrios, 1997).

Proven Hosts: These hosts are regulated because Koch's Postulates have been demonstrated, documented and reviewed. The parts of the host that are regulated depend on the tissues infected by the pathogen. Damage to timber, tourism, nursery industries and to the environment has been widely documented (Davidson *et al.*, 2003c). Details for selected hosts are listed below.

Caprifoliaceae: Caprifoliaceae includes important nursery and landscape species worldwide. One of the first hosts detected in Europe was *Viburnum x bodnantense* (Werres *et al.*, 2001). Infection by *P. ramorum* at the crown of *Viburnum* species causes stem cankers, which can result in plant death (Jones *et al.*, 2003).

Ericaceae; This family encompasses another important group of nursery and landscape plants, *e.g., Pieris formosa, Rhododendron* spp.. In addition, members of this family are important environmental, understory and small fruit production plants, *e.g., Calluna vulgaris, Rhododendron* spp., and *Vaccinium ovatum*, respectively.

Fagaceae: This family includes a variety of forest species. Members of the red/black oak group, *Quercus agrifolia*, *Q. parvula* var. *shrevei*, and *Q. kelloggii* (Rizzo *et al.*, 2002a, b), although not major timber species, are important to the environment and tourism. The red/black oak group

includes several important timber species on the east coast, *e.g.*, *Q. rubra*, and *Q. falcata* (Table 1). *Q. chrysolepis*, a member of Section Protobalanus, is also a natural host (Murphy and Rizzo, 2003; Davidson *et al.*, 2003a,c). At this time only two species of the white oak group have been found to be susceptible *Q. alba* and *Q. robur* (experimental hosts) (Brasier *et al.*, 2002; Jones *et al.*, 2003; Tooley and Kyde, 2003)). Another member of the Fagaceae, *Lithocarpus densiflorus* is unique in that stems (trunks), twigs and foliage are susceptible. This species is widely used for firewood (Davidson *et al.*, 2003c).

Pinaceae/Taxodiaceae: Other forest trees include two important timber species, *Sequoia sempervirens* (Taxodiaceae) and *Pseudotsuga menziesii* (Pinaceae). Only young tissue is regulated because infection in the field is limited to succulent growth (Chastagner *et al.*, 2004, 2005b; Davidson *et al.*, 2002a, 2004; Maloney *et al.*, 2002a, c).

Lauraceae: *Umbellularia californica* can be in important source of inoculum. Occurrence of *U. californica* is highly correlated with Phytophthora canker incidence in *Quercus* and *Lithocarpus* in California (Kelly and Meentemeyer, 2002; Meshriy *et al.*, 2005; Swiecki and Bernhardt, 2002a,b), but not in Oregon (Hansen *et al.*, 2005).

Theaceae: This family includes *Camellia* spp. which are important nursery and landscape plants. *Camellia* is regulated at the genus level because of the large number of species (ten) and hybrids (18) determined to be hosts (Beales *et al.*, 2004a; DA-2004-19 (June 23, 2004); Parke *et al.*, 2004a). *P. ramorum*-infected plants have been detected in domestic and international trade.

Associated Plants: Species symptomatic in a natural setting from which *P. ramorum* has been isolated but for which Koch's postulates have not been demonstrated, documented and reviewed are designated as Associated Plants (Table 1). Taxa are moved from the Associated Plant List to the Proven Host List when Koch's Postulates are demonstrated and reviewed (APHIS, 2005b).

Experimental Hosts: Pathogenicity tests have been conducted by inoculating intact and detached leaves, (Tooley *et al.*, 2004; Parke *et al.*, 2002b,c, 2005a), log sections (Brasier *et al.*, 2002; Hansen *et al.*, 2005), saplings (Rizzo *et al.*, 2002b; Tooley and Kyde, 2003), and by infested medium (Parke *et al.*, 2005b). These screening techniques are used to predict potential hosts (Parke *et al.*, 2005a), but hosts will not be added to the Proven Hosts or Associated Plants list unless found naturally infected.

Table 1. Plants listed as either Proven Hosts or Plants Associated with *Phytophthora ramorum* by the United States Department of Agriculture (10 January 2005).

Proven Hosts

Scientific Name	Common Name	Disease(s)	Plant Part(s) Infected
Aceraceae			
Acer macrophyllum	Bigleaf maple	Leaf blight	Leaf
Caprifoliaceae			
Lonicera hispidula	California honeysuckle	Leaf blight	Leaf
Viburnum x bodnantense	Bodnant viburnum	Canker	Stem, Flower
Viburnum plicatum var. *tomentosum*	Doublefile viburnum	Leaf blight, Dieback	Stem, Flower
Viburnum tinus	Laurustinus, Viburnum	Leaf blight, Dieback	Stem, Flower
Ericaceae			
Arbutus menziesii	Madrone	Leaf blight, Dieback	Branch, Leaf
Arctostaphylos manzanita (unconfirmed by isolation)	Manzanita	Leaf blight, Canker	Stem, Leaf, Twig, Branch
Calluna vulgaris	Heath	Dieback	Twig
Pieris formosa	Andromeda	Leaf blight, Dieback	Leaf, Twig
Pieris formosa x japonica 'Forest Flame'	Pieris 'Forest Flame. Forest flame andromeda'	Leaf blight, Dieback	Leaf, Twigs
Pieris floribunda x japonica	Pieris 'Brouwer's Beauty', Brouwer's beauty andromeda	Leaf blight, Dieback	Leaf, Twig
Pieris japonica	Japanese Pieris	Leaf blight, Dieback	Leaf, Twig
Rhododendron spp.	Rhododendron	Leaf blight, Dieback	Leaf, Twig, Stem
Vaccinium ovatum	Huckleberry	Canker, Dieback, Leaf blight	Main stem, Branch, Leaf
Fagaceae			
Lithocarpus densiflorus	Tanoak	Canker, Leaf blight	Stem, Branch, Leaf
Quercus agrifolia	Coast live oak	Canker	Stem
Quercus chrysolepis	Canyon live oak	Canker	Sapling, Stem
Quercus kelloggii	California black oak	Canker	Stem
Quercus parvula var. *shrevei*	Shreve oak	Canker	Stem
Hamamelidaceae			
Hamamelis virginiana	Witch-hazel	Leaf blight, Dieback	Leaf, Twig
Hippocastanaceae			
Aesculus californica	California buckeye	Leaf blight	Leaf, Twig
Lauraceae			
Umbellularia californica	California bay laurel, Oregon myrtlewood, pepperwood	Leaf blight	Leaf
Liliaceae			
Maianthemum racemosa (=Smilacina racemosum)	False Solomon's seal	Leaf blight	Leaf
Pinaceae			
Pseudotsuga menziesii var. *menziesii*	Douglas-fir	Leaf blight	Branch, Leaf
Primulaceae			
Trientalis latifolia	Western starflower	Leaf blight	Leaf
Rhamnaceae			

Scientific Name	Common Name	Disease(s)	Plant Part(s) Infected
Rhamnus californica	California coffeeberry	Leaf blight	Leaf
Rosaceae			
Heteromeles arbutifolia	Toyon	Leaf blight, Dieback	Branch, Leaf
Photinia fraseri	Red tip photinia		Leaf
Rosa gymnocarpa	Wood rose	Leaf blight	Leaf
Taxodiaceae			
Sequoia sempervirens	Coast redwood	Needle blight	Needle, Twig, Sprout
Theaceae			
Camellia spp.	Camellia	Leaf blight; less frequently dieback	Leaf, Petiole, Flower bud, Shoot, Twig

Associated Plants (regulated as Nursery Stock only)

Scientific Name	Common Name	Disease(s)	Plant Part(s) Infected
Anacardiaceae			
Toxicodendron diversiloba	Poison oak	Canker	Stem
Betulaceae			
Corylus cornuta	California hazelnut	Leaf blight	Leaf
Caprifoliaceae			
Viburnum davidii	David viburnum	Canker, leaf blight	Leaf, Stem, Flower
Viburnum farreri (=V. fragrans)	Fragrant viburnum	Canker	Stem, Flower
Viburnum lantana	Wayfaringtree viburnum	Canker	Stem, Flower
Viburnum opulus	European cranberrybush viburnum	Canker	Stem, Flower
Viburnum x burkwoodii	Burkwood viburnum	Canker	Stem, Flower
Viburnum x carlcephalum x V. utile	Viburnum	Canker	Stem, Flower
Viburnum x pragnense	Prague viburnum	Canker	Stem, Flower
Viburnum x rhytidophylloides	Alleghany or Willowood viburnum	Canker	Stem, Flower
Dryopteridaceae			
Dryopteris arguta	California wood fern	"Leaf blight"	Frond
Ericaceae			
Arbutus unedo	Strawberry tree	Leaf blight	Leaf
Kalmia latifolia	Mountain laurel	Leaf blight, Dieback	Leaf, Twig
Leucothoe fontanesiana	Dog hobble, Dog laurel	Leaf blight	Leaf
Pieris formosa var. *forestii*	Pieris	Canker	Stem
Pieris formosa var. *forestii x Pieris japonica*	Pieris	Canker	Stem
Fagaceae			
Castanea sativa	Sweet chestnut	Canker	Leaf, Stem
Fagus sylvatica	European beech	Canker	Bole
Quercus cerris	European turkey oak	Canker	Bole
Quercus falcata	Southern red oak	Canker	Bole
Quercus ilex	Holms oak	Dieback	Sprout

Scientific Name	Common Name	Disease(s)	Plant Part(s) Infected
Quercus rubra	Northern red oak	Canker	Bole
Hippocastanaceae			
Aesculus hippocastanum	Horse chestnut	Canker	Bole
Lauraceae			
Laurus nobilis	Sweet bay laurel	Leaf blight	Leaf
Liliaceae			
Clintonia andrewsiana	Andrew's clintonia bead lily	Leaf blight	Leaf
Nothofagaceae			
Nothofagus obliqua	Roble beech, Southern beech	Canker	Bole
Oleraceae			
Fraxinus excelsior	European Ash	Canker	Bole
Syringa vulgaris	Lilac	Leaf blight	Leaf
Pinaceae			
Abies grandis	Grand fir	Dieback	Branch, Needle
Pittosporaceae			
Pittosporum undulatum	Victorian box	Leaf blight	Leaf
Rhamnaceae			
Rhamnus purshiana	Cascara	Leaf blight	Leaf
Rosaceae			
Pyracantha koidzumii	Formosa firethorn	Leaf blight	Leaf
Rubus spectabilis	Salmonberry	Leaf blight	Leaf
Salicaceae			
Salix caprea	Goat willow, Kilmarnock willow	Leaf blight, Dieback	Leaf, Twig
Taxaceae			
Taxus baccata	European yew	Dieback	Twigs at buds
Taxus brevifolia	Pacific yew	Dieback	Needle, Twig
Winteraceae			
Drimys winteri	Winter's bark	Leaf blight, Dieback	Leaf, Twig

* If hosts are used as nursery stock, the entire plant is regulated. If selected plant parts, *e.g.*, leaves for wreaths, wood for timber, the actual plant parts are the regulated articles.

C. GEOGRAPHIC DISTRIBUTION

Asia: No record
Africa: No record
Caribbean: No record
Central America: No record
Oceania: No record
South American: No record

Europe: The fungus was reported in Belgium, Denmark, France, Germany, Ireland, Italy, Netherlands, Poland, Spain (Mallorca, Islas Baleares), Slovenia, Sweden, Switzerland and United Kingdom (EPPO, 2004). The organism has been found on *Quercus* in public and private gardens near infected *Rhododendron* in The Netherlands (EPPO, 2004) and the United Kingdom (Brasier, 2002).

North America:
Mexico: No record.
Canada: Infected nursery stock has been detected and destroyed in British Columbia.

United States: The disease was confirmed and is regulated in 14 counties in California (Alameda, Contra Costa, Humboldt, Lake, Marin, Mendocino, Monterey, Napa, San Francisco, San Mateo, Santa Clara, Santa Cruz, Solano, and Sonoma) and nine square miles in Curry County, Oregon (7 CFR § 301.92). Infected nursery stock has been detected and destroyed in the following states: Alabama, Arkansas, Arizona, California (non-regulated portions), Colorado, Connecticut, Florida, Georgia, Louisiana, Maryland, North Carolina, New Jersey, New Mexico, New York, Oklahoma, Oregon, Pennsylvania, South Carolina, Tennessee, Texas, Virginia and Washington (APHIS, 2005a). As of January 10, 2005, all nursery stock shipped from California, Oregon and Washington State are regulated to prevent movement of this pathogen (Agric. Dep't. Emergency Federal Order (Dec. 21, 2004))

D. BIOLOGY and EPIDEMIOLOGY

The disease cycle associated with *Phytophthora ramorum* (Fig. 1) is complex because of the variety of habitats where the disease occurs and the diversity of plants attacked and their responses to infection (Davidson *et al*., 2003c). Three different diseases have been described (Hansen *et al*., 2002): Phytophthora canker (sudden oak death), *e.g*., on several members of Fagaceae; ramorum leaf blight, *e.g*., on *U. californica*; and ramorum dieback, *e.g*., on *Q. ilex.*

Phytophthora ramorum produces sporangia, zoospores and chlamydospores in culture and in nature (Davidson *et al.*, 2003c; Parke *et al.*, 2002a; Werres *et al*., 2001), and oospores under laboratory conditions (Werres and Zielke, 2003). Sporangia are semi-papillate, deciduous (caducous) and range in length from 20-80 µm (Werres *et al.*, 2001; Rizzo *et al.*, 2002b). Chlamydospores are produced on hyphal tips, are hyaline becoming brown with age and when produced on host tissue (Rizzo *et al.*, 2002b; Werres *et al.*, 2001). Chlamydospores range in size from 40-80 µm (Rizzo *et al.*, 2002b) and 20-91 µm (Werres *et al.*, 2001). Hyphae of this species

are nodose, highly branched, contorted, and form a dendritic pattern. *P. ramorum* is a poor saprophytic competitor (Rizzo *et al.*, 2002b).

A heterothallic organism, *P. ramorum* has two mating types, A1 and A2 (Werres *et al.*, 2001). Originally, A1 isolates were found in Europe (Werres *et al.*, 2001) and A2 isolates in the United States (Rizzo *et al.*, 2002b). The two mating types coincided with genetic differences and were determined to be distinct populations (Kroon *et al.*, 2004). In 2003, an A2 isolate was detected on imported European nursery stock in Belgium which matched the European population (Werres and De Merlier, 2003). Also in 2003, A1 isolates were detected on nursery stock in Oregon, Washington and British Columbia which matched the European A1 population (Hansen *et al.*, 2003). Most recently, a new A2 isolate was detected on nursery stock in Washington State. Some alleles of this isolate are identical to the European population and some to the North American populations (Matteo Garbelotto, pers. comm.).

Oospores have not been detected in nature, but have been observed in culture when *P. ramorum* strains are paired with other *Phytophthora* species representing opposite mating types (Werres *et al.*, 2001; Rizzo *et al.*, 2002b). Recently oospores were reported on hyphae produced from a pairing of U.S. isolate PR6-2 with EU isolate BBA 9/95 on green *Rhododendron* twigs (Zielke and Werres, 2002).

In culture, *P. ramorum* had optimum growth at 20°C (Werres *et al*., 2001), reduced growth at -1°C, and did not survive -25°C (DEFRA, 2004c). However, one North American A2 isolate was found to grow optimally at 25°C (DEFRA, 2004c). There is limited information available on infection by *P. ramorum*. Detached leaf assays of *Rhododendron* found a positive correlation between lesion development and number of degree days; 25°C, the maximum temperature tested, resulted in the largest lesions (DEFRA, 2004c). Garbelotto *et al.* (2003) found that 9-12 hours of leaf wetness at 18°-22°C are necessary to obtain significant infections on *U. californica* leaves. Lewis and Parke (2005) observed *P. ramorum* penetrating *Rhododendron* roots at primordia, emerging laterals and wound sites. They also noted that *P. ramorum* did not need stomata to infect leaves and that infections near the midrib resulted in more rapid disease development than infections at other leaf sites.

Hosts of *P. ramorum* usually fall into one of two disease categories, “canker hosts” or “leaf and twig hosts” (Davidson *et al.*, 2003c). The pathogen is polycyclic (Fig. 1) on most leaf and twig hosts (Davidson *et al.*, 2003 a, b, c). Infections in leaf and twig hosts are rarely fatal, but they are a reservoir of the pathogen and source of inoculum (DEFRA, 2004c; Parke *et al.*, 2002b,c; Rizzo *et al.*, 2002b). Sporangia and chlamydospores are produced abundantly on several foliar and dieback hosts including *U. californica* (Davidson *et al.*, 2002b), *Rhododendron*, and *Kalmia latifolia* (DEFRA, 2004c). Differences in sporulation ability and susceptibility to infection have been reported for foliar and dieback hosts (Dodd *et al*., 2002b; DEFRA, 2004c; Hüberli *et al.*, 2002b; Hansen *et al.*, 2005; Parke *et al.*, 2002a, b, c, 2005a).

In field tests, chlamydospores within host material were shown to overwinter down to -9°C in the UK (DEFRA, 2004c), and to oversummer in California (Fichtner *et al.*, 2004, 2005b). Chlamydospore survival increased with depth of burial in both studies (DEFRA, 2004c; Fichtner *et al.*, 2005b).

Canker hosts exhibit infections on basal stems (tree trunks, crowns of *Viburnum*) and often die. Sporulation was not observed on canker surfaces of these hosts (Davidson *et al.*, 2003b, c), though exudates have tested positive with PCR. However, if the inner bark (cambium) is exposed and free water is present, the pathogen can sporulate on exposed surfaces (Davidson *et al.,* 2003b, c). The pathogen has been recovered from inner bark (Davidson *et al.,* 2003b), wood chips (Davidson *et al.*, 2003c; Shelly *et al.*, 2005b) and from firewood stored for 6 months (Shelly *et al.,* 2005a). Sporulation in baiting trials was stimulated when inoculated "logs" were kept at 12°C prior to baiting (Matteo Garbelotto, pers. comm.).

The disease incidence of Phytophthora canker in California and Oregon is clustered. Spatial analysis in California indicated that diseased plants were clustered within 100 and 300 m of each other (Meentemeyer and Kelly, 2002). Disease incidence was correlated with proximity to forest edge, potential topographic moisture, abundance of *U. californica*, and potential solar radiation.

Long distance dispersal includes movement of infected plant material (wood, green material products, and nursery stock), soil, water (rain, runoff, streams, rivers, irrigation water) (Davidson *et al.*, 2002b, 2002c, 2002e), animals, and aerial dissemination (of sporangia, zoospores and possibly chlamydospores) during major weather events. It is postulated that long distance dispersal through aerial dissemination is responsible for spread of the A2 mating type in U.S. (Hansen *et al.,* 2002).

Proposed disease cycle for *Phytophthora ramorum*

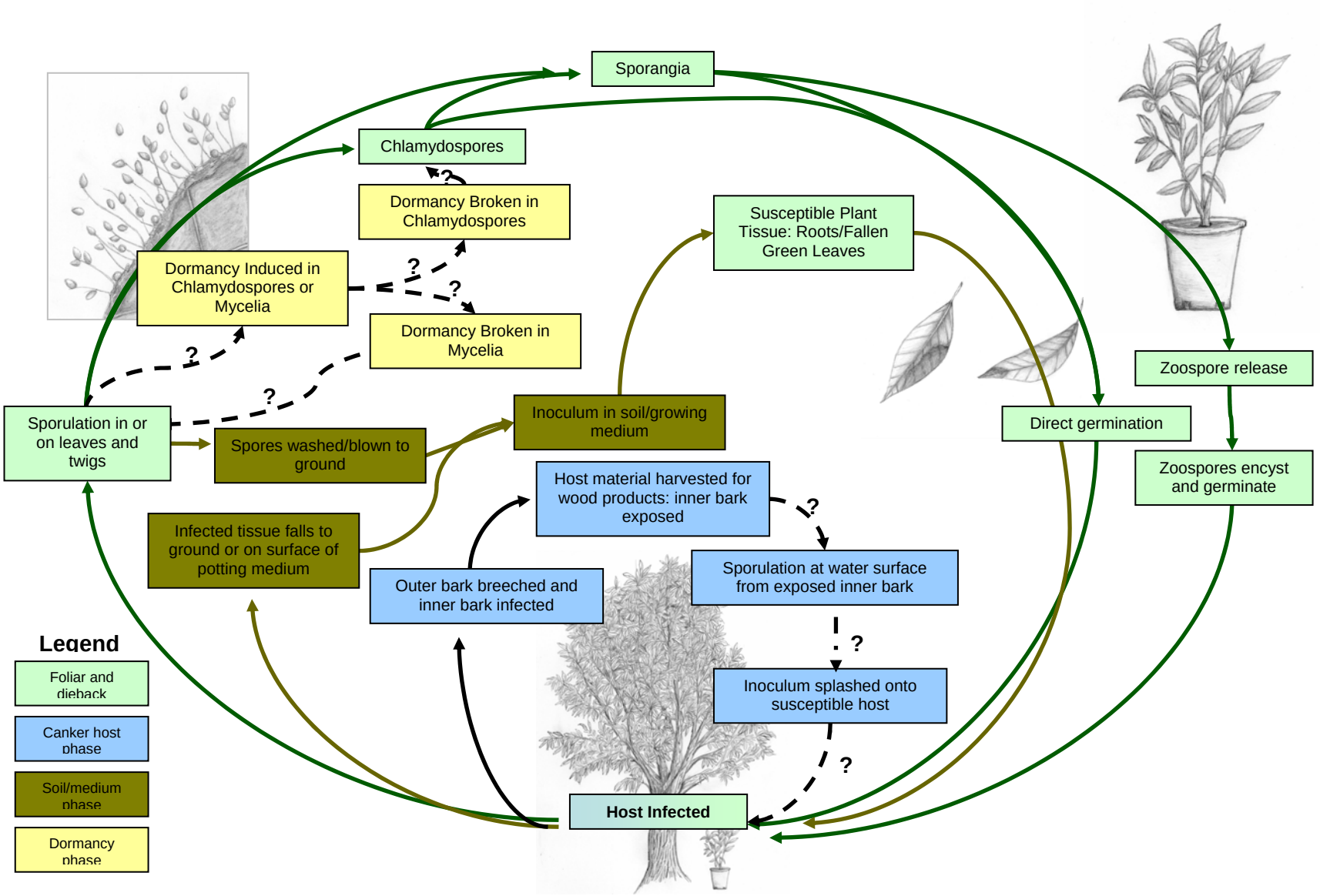

Fig. 1. Proposed disease cycle for Phytophthora canker (sudden oak death), leaf blight and dieback. Color is used to designate different hosts and phases

E. DETECTION AND IDENTIFICATION

Symptoms

Three different diseases are attributed to *P. ramorum*: stem or bole canker, twig blight (dieback) and leaf blight. Symptomology has been addressed by Davidson *et al.* (2003b); Garbelotto *et al.* (2002a, 2003); Parke *et al.* (2003, 2004b); Storer, *et al*. (2002); and Tjosvold *et al*. (2004).

Hosts which are prominent in the nursery trade include *Rhododendron, Camellia, Pieris* and *Viburnum*. Symptoms on *Rhododendron* unfortunately mirror those incited by other species of *Phytophthora* and by certain environmental factors, making inspection for the disease more complicated (Davidson *et al.*, 2003b) and detection more challenging (Jones, *et al*., 2005).

With *Lithocarpus* species, drooping or wilting of new growth occurs before other symptoms appear (Storer *et al.*, 2002). Cankers typically occur in the lower 3 meters and are restricted to above the soil line. Occasionally cankers have been found 20 meters above ground. Cankers can eventually kill the tree by attacking the phloem and girdling the tree. Bleeding symptoms of the canker are easier to detect during dry weather and become more difficult to detect during the rainy season.

Two new *Phytophthora* species, *P. nemorosa* and *P. kernoviae (*proposed name) were found as a result of field analyses for *P. ramorum*. *P. nemorosa* occupies a similar ecological niche to *P. ramorum* in the U.S. (Hansen *et al.,* 2003b) and *P. kernoviae* a similar niche in the U.K. (DEFRA, 2004c, 2005a).

Isolation, Detection and Characterization

Phytophthora ramorum can be isolated directly or indirectly (baiting with pear fruit or host leaves) from infected host material, soil and water (Davidson *et al.*, 2002a, 2003b; Goheen *et al.*, 2002d; Jones, *et al.,* 2003; Maloney *et al.*, 2002a; Rizzo *et al.*, 2002a, b; Werres *et al.*, 2001). Recovery rates vary with season and host (Davidson *et al.*, 2003b; Hayden *et al.,* 2004; Garbelotto, pers. comm.). and are facilitated with the use of the selective medium, PARP (Davidson *et al.*, 2003b). Additionally, preliminary results indicate that exposure of infected woody material to a cool temperature, 12°C, (Matteo Garbelotto, pers. comm.), and plating the samples on PARP immediately following collection in the field (Storer *et al.*, 2002) will facilitate recovery of the pathogen . Samples are cultured in the dark at 20^{o} to 22^{o}C and examined within seven days.

Morphological and molecular comparisons of U.S. and EU isolates indicate that the two mating types are the same species (Ivors *et al.*, 2004*;* Man in't Veld *et al.*, 2002; Zielke and Werres, 2002). Pogoda and Werres (2002) found that colony morphology and growth rate were related to aggressiveness. Slow vegetative growth, exhibited by many U.S. isolates, was correlated with mild twig infection. Although the UK isolates have greater genetic diversity than the U.S. isolates, they are more phenotypically similar than the U.S. isolates.

Polymerase chain reaction (PCR) methods are used for the detection and identification of this pathogen (Martin and Tooley, 2002; Hayden *et al.*, 2004). Hayden *et al*. (2004) found PCR and isolation frequency varied with season and host, but PCR detection was more sensitive than

isolation. Maloney *et al.* (2004) first detected *P. ramorum* in madrone by PCR and later were able to isolate the pathogen. *Arctostaphylos manzanita* was found to be positive by PCR but isolation attempts were unsuccessful (Rizzo *et al.,* 2002a).

Molecular analysis found that 85 isolates (65 U.S., 18 European) were identical at three DNA regions (ITS, *cox* II and *nad* 5) (Ivors *et al.,* 2004). Amplified Fragment Length Polymorphism (AFLP) analysis indicated that a single clonal lineage dominated the U.S. isolates. Two U.S. isolates from an Oregon nursery differed at those regions. Microsatellite analysis of over 200 isolates revealed seven loci that discriminated between U.S. and European isolates (Prospero *et al.,* 2005). Microsatellite analysis of the two Oregon nursery isolates revealed loci identical to the U.S. and European populations, as well as unique loci, indicating that these isolates are distinct (Matteo Garbelotto, pers. comm.).

Two available techniques were assessed to determine an appropriate protocol for the U.S. National Nursery Survey (Laurene Levy, pers. comm.). A real-time PCR method is used for regulatory purposes in both the U.S. and the U.K.. The ITS DNA analysis does not always distinguish *P. ramorum* from *P. lateralis,* however, multiplex methods can increase sensitivity.

Remote sensing, Aerial and Ground Surveys

Aerial surveys have been used to survey for damaged *L. densiflorus* in Oregon (Goheen *et al.,* 2002e) and for *Quercus* spp. and *L. densiflorus* in California (Levien *et al.,* 2002). Airborne Digital Acquisition and Registration (ADAR) imagery based on red, green, blue and near infrared wavelengths was tested for capability to map species (Kelly and Meentemeyer, 2002). Results were variable, but more promising for species mapping than for locating moisture stressed trees.

IV. ORGANISM RISK ASSESSMENT

A. PRIOR RISK ASSESSMENTS, CURRENT STATUS AND INTERCEPTIONS

As an emergency response to *P. ramorum* confirmations in California and Oregon, an Interim Rule was promulgated (65 Fed. Reg. 56803-56806) on February 14, 2002. The U.S. Forest Service conducted a risk assessment in 2000 and updated it in 2001, 2002, and 2003 (Kliejunas, 2003). Other risk analyses have been produced by the Canadian Food Inspection Agency (2001), the U.K. Department of Environment, Forestry and Rural Affairs (2002, 2003) and the Oregon Department of Agriculture (2001).

Phytophthora spp. are difficult to detect by visual inspection, and have only been intercepted at U.S. ports of entry seven times since January 1, 1985. None of the interceptions were on a regulated or associated host of *P. ramorum,* but several were on close relatives. Plant Inspection Stations at various U.S. ports of entry have now been supplied with ELISA kits to augment detection of *P. ramorum* (Jonathan Jones, pers. comm.).

B. CONSEQUENCES OF INTRODUCTION

This portion of the assessment considers negative outcomes that may occur when the hosts of *Phytophthora ramorum* provide a pathway of entry into the United States from infested countries as well as domestic movement of infested plant material. The potential consequences are evaluated using five Risk Elements (APHIS, 2000): Climate-Host Interaction, Host Range, Dispersal Potential, Economic Impact, and Environmental Impact. These risk elements reflect the biology, host range and climatic and geographic distribution of this pathogen, and are supported by biological information. For each risk element, a rating of Low, Medium, or High is assigned (APHIS, 2000). Additionally, specific pathways, *i.e.*, plants for planting, wood, soil, potting media, cut flowers/foliage, greenwaste and consumption, will be evaluated using these Elements.

Risk Element 1: Climate/Host Interaction

This risk element considers ecological zonation and the interactions of *P. ramorum* with its hosts in a variety of environments. When introduced into new areas, pests are expected to behave as they do in their native areas if the potential host plants and suitable climate are present. Broad availability of suitable climates and a wide distribution of suitable hosts are assumed to increase the impact of a pest introduction. The ratings for this risk element are based on the relative number of United States Plant Hardiness Zones (USDA, 2003).

Phytophthora ramorum has a high probability of encountering favorable climatic conditions throughout the ranges of potential hosts. Modeling of environmental conditions suggests that there are many areas in the U.S. which have both favorable conditions for disease development and susceptible hosts (Smith *et al*., 2002; Magarey *et al.,* 2004) (Fig. 2). Climate potential was higher on the west coast and east of the Mississippi River than in the Central Plains of the U.S. The risk to the more arid Central Plains States increases when humid microclimates are created. This occurred during 2003 and 2004 in California when nurseries outside the quarantine zone, and in a more arid and warmer environment, shipped infected nursery stock (Magarey *et al.,* 2004).

The risk rating is High for the Climate-Host Interaction Risk Element. The level of certainty for this risk rating is fairly certain. Most of the eastern U.S. has actual and potential hosts in climates conducive for infection. The uncertainty lies in the range of biotic and abiotic factors triggering establishment of *P. ramorum* in new areas.

Risk Element 2: Host Range

The risk posed by a plant pest depends on both its ability to establish a viable, reproductive population and its potential to damage plants. This risk element assumes that the consequences of pest introduction are positively correlated with the pest's host range. Aggressiveness, virulence and pathogenicity also may be factors. The consequences related to host range are

rated in accordance with the ability of the pathogen to attack a single species or multiple species within a single genus, a single plant family, or multiple families.

The host range of this pathogen continues to expand though detections in the field. APHIS currently has 31 regulated and 37 associated hosts in 22 plant families (Table 1). The potential host range is also increasing (DEFRA, 2004b; Hansen *et al.,* 2005). Experimental evidence demonstrates that several eastern forest species would be more susceptible than western forest species. In addition, differences in host susceptibility are documented for forest and nursery species and may impact disease development in new environments (DEFRA, 2004c; Meshriy *et al.,* 2005; Tooley *et al.,* 2004).

Tree species in the red oak/black oak group appear to be highly susceptible to *P. ramorum*. Greenhouse studies have compared susceptibility of regulated *Quercus* species to non-regulated *Quercus* species. Two- to three-year old seedlings of *Q. alba*, an important white oak species of the eastern forest, as well as seedlings of *Q. rubra, Q. prinus*, and *Q. falcata* var. *pagodifolia* were found to be as susceptible to *P. ramorum* as the regulated host, *Q. agrifolia* (Tooley and Kyde, 2003).

Brasier *et al.* (2002) have screened several forest species by inoculating the inner bark of logs with isolates of U.S. and EU of *P. ramorum.* This study suggested the most susceptible species in the UK are *Q. rubra, Q. cerris, Q. ilex, Fagus sylvatica, Castanea sativa, Picea sitchensis, Pseudotsuga menziesii* var. *menziesii,* and *Chaemaecyparis lawsonia.* Since the study was completed, several of those species have been found naturally infected by *P. ramorum* during surveys in Europe: *Q. rubra* in the Netherlands, and *Q. falcata, Q. ilex, Q. cerris, Fagus sylvatica,* and *Aesculus hippocastanum* in the UK (DEFRA, 2004b).

White oak species, *Q. douglasii*, *Q. lobata*, and *Q. robur* are not as susceptible to *P. ramorum* as red oak species (Brasier *et al*., 2002*;* Rizzo *et al.,* 2002a). Lesions on young white oak trees were similar in size to those on the wounded noninoculated trees.

The large number of hosts, in multiple plant families, differential susceptibility and virulence warrant a risk rating for Host Range of High. The level of certainty for this risk rating is High. *P. ramorum* already has a large demonstrated host range. The uncertainty for the rating for this element lies in not knowing the extent of the host range.

Fig. 2. Overall risk index for the establishment of *Phytophthora ramorum* in the United States based on introduction potential (includes number of plants shipped from an infested nursery), climate potential (leaf wetness, temperatures and RH base on 30 year averages), economic potential and host strength (quantity and diversity of potential hosts) (Magarey *et al.*, 2004).

Risk Element 3: Dispersal Potential

Pests may disperse after introduction into new areas. The dispersal potential indicates how rapidly and widely the pests may spread may be expressed within the importing country or region and is related to the pest's reproductive potential, inherent mobility, and external dispersal facilitation modes. Factors for rating the dispersal potential include: the presence of multiple generations per year or growing season, the relative number of offspring or propagules per generation, any inherent capabilities for rapid movement, the presence of natural barriers or enemies, and dissemination enhanced by wind, water, vectors, or human assistance.

The scattered pattern of sites where *P. ramorum* has become established suggests that it has a mechanism of spread over large areas. Strong winds common during heavy rains along the California coast may move the easily detached sporangia great distances (Hansen *et al.*, 2002). Initial survey results in California and Oregon indicate *P. ramorum* is in streams and rivers adjacent to and far from known infested areas (Murphy *et al.*, 2005; Hansen *et al.*, 2005).

Inoculum has been detected seasonally from soil in hiking trails and from soil on hikers' boots (Davidson *et al.*, 2002c; Tjovold *et al.*, 2002b). The concern for soil and litter movement by equipment has promoted California authorities to request that vehicles and other equipment including tents and shoes leaving an established area be washed before leaving the area (COMTF, 2004a).

Confirmed positive sites from the trace forward, national, and other survey total 176 in 22 States (APHIS, 2005c,d). The total includes three residential finds (Georgia, South Carolina) and one positive determination in the environs (New York). As of January 10, 2005, all nursery stock shipped from California, Oregon and Washington State are regulated to prevent movement of this pathogen (Federal Order 21 December 2004). In 2004, 665 Christmas tree plantations in Oregon and 100 in Washington State were surveyed and found negative for *P. ramorum* (COMTF, 2004b).

Many of the hosts on the regulated and associated host lists are major nursery, forest and understory species (Bailey *et al.,* 1976), and the host range is expanding though detections in the field. Evidence exists that several eastern forest species would be as susceptible as affected species in California and Oregon. Additionally, environmental conditions in areas in the eastern U.S. are predicted to be more conducive for disease development than in the majority of the western U.S. (Magarey *et al.*, 2004).

Newly established populations may go undetected for years. The disease was first noted in California in 1995 (Garbelotto *et al.*, 2001). With rate of oak death, researchers suggest the pathogen was introduced at least five years before the first detection (Rizzo and Garbelotto, 2003).

In the United States, both regulated and associated hosts are widely distributed, overlapping, abundant and susceptible. In addition, the pathogen is polycyclic, infections may remain undetected for years, and there is demonstrated long distance dispersal via trade and circumstantial evidence by natural means. For these reasons, the Dispersal Potential rating for *P. ramorum* is High. The level of uncertainty for this rating is low based on the evidence of human assisted and natural movement.

Risk Element 4: Economic Impact

Introduced pests cause a variety of direct and indirect economic impacts, such as reduced yield, reduced commodity value, loss of foreign or domestic markets, and non-crop impacts. Factors considered during the ranking process include: effect on yield or commodity quality, plant mortality, ability to act as a disease vector, increased costs of production including pest control costs, lower market prices, effects on market availability, increased research or extension costs, or reduction in recreational land use or aesthetic value, hosts or products with significant commercial value, organism directly causes tree mortality or predisposes host to mortality by other organisms, damage by organism causes a decrease in value of the host affected, for instance, by lowering its market price, increasing cost of production, maintenance, or mitigation, or reducing value of property where it is located, and lack of effective control measures.

California's oak woodlands contain about 5 billion cubic feet of wood valued at over $275 million (Kliejunas, 2003). The nearby California timberlands contain 5.8 billion cubic feet of oaks, which are worth over $500 million for forest products alone (Kliejunas, 2003). Oak products exported from California from 1996-2000 averaged almost $50 million per year (USITC, 2005).

There is potential economic threat to eastern U.S. oaks. Two oak species native to eastern U.S., *Quercus rubra* and *Q. falcata,* were found naturally infected in Europe (EPPO, 2004). Susceptibility of other eastern U.S. tree species (*Q. alba, Q. laurifolia, Q. nigra, Q. pagoda, Q. phellos, Q. prinus, Q. virginiana, Acer saccharum,* and *Juglans nigra*) has been experimentally demonstrated (Brasier *et al.,* 2002; Tooley and Kyde, 2004), and represents a potential economic threat to commercial timber production in the U.S. exceeding $30 billion (Kliejunas, 2003). The export value of red oak logs and lumber was over $300 million dollars in 2002 (USITC, 2005).

In coastal central California, oak woodland suitable for residential development has been estimated at $20,000 per acre; rangeland with at least 40 oaks per acre was worth 27 percent more than open land (Standiford, 2000 in Kliejunas, 2003). In southwestern Oregon, mature black oak trees can increase property values by $5,000-30,000 (Osterbauer, 2003).

Economic losses from removal of infected *Quercus* and *Lithocarpus* trees may be partially offset by utilization of the material for wood products. Current regulations require debarking of the logs in order to send them to pulp mills outside quarantine areas (COMTF, 2003a). Hardwood hosts are used for firewood, wood chips for pulping, compost, non-grade lumber, and charcoal. Higher value uses include custom furniture, flooring, cooperage and tool handles (Shelly *et al*., 1996).

The U.S. nursery industry is also at risk. Nursery crops include woody perennial plants, such as ornamental trees, shrubs, and vines, which are primarily used for landscaping. In 2003, the U.S. domestic production of nursery crops was valued about $9.2 billion. Imports for these crops were $483 million and exports were $210 million (Jerado, 2004).

Tourism is also impacted. Visitors to parks and forests are impacted because access to selected areas may be restricted during certain seasons to prevent movement of the pathogen, or to protect visitors from falling limbs from trees killed by *P. ramorum*. When visitors are requested or required to take precautions to prevent movement of the pathogen, park and forest staff maybe required to provide educational information, staff cleaning areas, and provide appropriate supplies and equipment to remove soil from shoes and vehicles.

The presence of *P. ramorum* has resulted in restrictions in foreign and domestic trade. Canada, Korea, Australia, New Zealand, and the European Union have placed restrictions on the movement of affected plants and plant parts from the U.S. (Jonathan Jones, pers. comm.; Rizzo and Garbelotto, 2003). In addition, the U.S. has placed restrictions on movement of propagative material from the EU (Karen Ackerman, pers. comm.).

The evidence, to date, is that *P. ramorum* is impacting the domestic movement of plants and plant products (nursery stock, fruit, logs, lumber, *etc*.) and has caused restrictions in international trade. For these reasons, the economic impact of *P. ramorum* is rated High. Uncertainty stems from unknowns regarding the extent of the host range and the value of these plants on the open market.

Risk Element 5: Environmental Impact.

The ratings for this risk element are based on three aspects: the potential of the pest to disrupt native ecosystems and the habits exhibited within its current geographic range; the need for additional chemical or biological control programs due to the presence of the pest; and the potential of the pest to directly or indirectly impact species listed as Threatened or Endangered (50 CFR § 17.11-12) by infesting or infecting a listed plant. When a pest is known to infest or infect other species within the same genus, and host specificity data does not exist for the listed plant, then the listed plant is assumed to be a potential host.

In forests, more than 20 non-indigenous species of plant pathogens attack woody plants (Liebhold *et al*. 1995). Two of the most destructive plant pathogens are *Cryphonectria parasitica* and *Ophiostoma ulmi*, the causal agents of chestnut blight and Dutch elm disease, respectively. Before the introduction of chestnut blight, approximately 25% of eastern U.S. deciduous forest consisted of American chestnut (*Castanea dentata*) trees (Liebhold *et al.*, 1995). These trees have all but disappeared. In urban and forest environments, species and cultivars of *Ulmus* have been destroyed by *O. ulmi*. Losses in real estate value and costs of removal and disease management are estimated to be about $100 million/year (Stipes and Campana, 1981). In addition, plant pathogens of forest plants cause the loss of approximately 9%, or $7 billion, of forest products each year (Hall and Moody, 1994; USBC, 1998). The proportion of introduced plant pathogens in forests is similar to that of introduced insects (about 30%), thus, approximately $2.1 billion in forest products are lost each year to non-indigenous plant pathogens in the United States. In addition to the direct costs of the prevention, eradication or suppression of this pathogen, the economic costs must also include indirect ecological consequences (perturbations of hydrological cycles, *e.g.*, flood control and water supply, waste assimilation, nutrient recycling, conservation and regeneration of soils, crop pollination) and must address both current-use value and future-use values.

Quercus species are the most important and widespread of the hardwood trees in the North Temperate Zone (Pavlik *et al.*, 1991, as cited in Kliejunas, 2002). These woodlands yield important benefits, *e.g.*, water and watershed protection, grazing, wildlife food and habitat, recreation, and wood products (Thomas, 1997, as cited in Kliejunas, 2002), are known for their scenic beauty, contribute to tourism and high property values and are valued for shelter and food for wildlife. The loss of keystone *Quercus* species in these forests would be detrimental to forest health. In addition, the effects on rare and endangered plant species in these regions are unknown. *Phytophthora ramorum* is expected to cause significant direct environmental effects such as extensive ecological disruption or large-scale reduction of biodiversity. This pathogen has already caused environmental damage with the death of thousands of *Quercus* and *Lithocarpus*. The effect of the loss of these trees on animal populations and the risk from fire hazard are being researched. Data exist that bird populations are affected with a change in species densities, but the total impact is unknown.

A number of genera on the APHIS List of Hosts and Associated Plants have species on the U.S. Fish and Wildlife Services Threatened and Endangered Species list. These are *Rhododendron*

chapmanii , Quercus hinckleyi, Arctostaphylos confertiflora, A. glandulosa ssp. crassifolia, A. hookeri var. *ravenii, A. morroensis, A. myrtifolia,* and *A. pallida*.

The rating for Environmental Impact is High. The uncertainty lies with the difficulty in producing estimates for the costs of *P. ramorum* that address all of the relevant ecological components. These include: (1) the direct costs of the prevention, eradication or suppression; (2) the economic costs, *e.g.* current-use-and future-use values; and (3) the indirect ecological consequences (changes in locally important ecological processes such as perturbations of hydrological cycles, *e.g.*, flood control and water supply; waste assimilation; nutrient recycling, conservation and regeneration of soils; and crop pollination).

C. LIKELIHOOD OF INTRODUCTION

The Likelihood of Introduction for a pest is rated relative to three factors and is a modification of APHIS PRA guidelines (APHIS, 2000). The assessment rates are based on three factors. The first factor, Entry Potential, is composed of the volume of materials moved domestically and internationally, the value of these shipments, and the likelihood that the pathogen survives post harvest treatments and shipment. The second factor, Establishment and Spread Potential, includes the likelihood that the pathogen will be imported or moved to an area suitable for survival and will encounter host material. The third factor, Detection Potential, is an estimation that the pathogen is not detected at ports-of-entry or during domestic inspections.

subelement 1: Entry Potential

The rating for this risk element is based on the volume and value of domestic shipments and of imports from Europe and Canada and on the ability of the pathogen to survive postharvest treatments and shipment. The volume of plants for planting from Europe increased from approximately 33 million plants in 2000 to 47 million plants in 2003, and dropped to 38 million plants in 2004 (Table 3), the drop possibly a result of restrictions on the imports of regulated hosts.

Live plants are grown, shipped and sent to areas conducive to their survival. Plant products, such as cut flowers and foliage will also be treated in ways not detrimental to the survival of *P. ramorum*. For example, *P. ramorum* has been detected in nursery stock shipped from California to 21 other states and eradicated in nurseries in which it was detected. In addition, models (Smith *et al.,* 2002; Magarey *et al.,* 2004) have indicated that most of the eastern U.S. has both potential hosts and favorable conditions (Fig. 3).

Living plants are not likely to receive postharvest treatments such as irradiation, methyl bromide, or steam sterilization. The types of treatments that would kill pests are also likely to kill the plants. In addition, the presence of potting media requires specific testing to ensure the efficacy of any proposed post-harvest treatments (Jarvis, 1992). General transport conditions for potted plants range from 10-18 °C and 85-90 R.H. (McGregor, 1987). *P. ramorum* has an optimum

temperature range between 18-25 °C (Werres *et al.*, 2001; DEFRA, 2004c) and survives temperatures as low as -9°C (DEFRA, 2004c).

Other infested plant products, such as logs, lumber, wood chips and firewood, though not handled as gently as live plants and cut flowers/foliage, still harbor the pathogen and present a pathway for introduction into new areas. For example, *P. ramorum* has been recovered from inner bark and wood chips (Davidson *et al.*, 2003b) suggesting that when the inner bark is exposed, as in the debarking process, and free water is present, the pathogen can sporulate on the exposed surfaces. Additionally, sporulation was stimulated in baiting trials when inoculated "logs" were kept at 12°C prior to baiting (Matteo Garbelotto, pers. comm.) and the pathogen has been recovered from fire wood stored for 6 months (Shelly *et al.*, 2005a).

Table 2. US Federal budget for detection and management of *Phytophthora ramorum* National Program.[1]

Fiscal Year	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Program Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Surveys	413	1,000	7,200	8,900	8,000	8,000	2,000
Quarantine	413	809	4,685	7,600	7,000	7,000	3,000
Forest Service				2,600	2,500	2,500	1,000
Scientific Support			2,000	1,875	1,700	1,700	1,000
Public Outreach			500	842	800	800	1,000
Total	826	1,809	14,385	21,817	20,000	20,000	8,000

NOTE: Program costs beyond FY 2008 are estimated to remain at $8 million per year.

[1] Data from sudden Oak Death and Other Plant Diseases Caused by Phytophthora ramorum: A National Strategic Plan. US Forest Service .

Table 3. Imports of Plant Materials from Europe and Canada to the United States (Quantity in 1000 units; Value in $1000 U.S.)*

VALUES IN 1000 DOLLARS/QUANTITIES IN REPORTED VOLUMES

JANUARY – DECEMBER

ORIGIN AND COMMODITY	2000		2001		2002		2003		2004	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
EUROPEAN UNION – 25										
Unrooted Cuttings/Slips, No Soil	19,573.50	3,817	19,162.30	3,793	20,874.80	3,895	27,100.90	4,910	23,340.50	4,945
Other Plants, With/Soil	12,941.20	3,399	14,486.20	2,791	14,934.50	3,430	15,463.10	4,725	13,531.00	4,155
Trees/Shrubs, With/Soil	186.6	269	545	651	370.4	553	269.4	714	209.7	610
Roses	286.5	463	627	744	818.1	1,429	415.5	778	294.4	493
Other Plant, With/Soil	200.7	112	199.3	88	141.2	22	3,173.80	336	943.9	300
Rhododendrons,Azaleas	90	8	96	12	31	3	0	0	0	0
Total	33,278.50	8,068.00	35,115.80	8,079.00	37,170.00	9,332.00	46,422.70	11,463.00	38,319.50	10,503.00
CANADA										
Oth Plant,W/S	119,206.40	85,636	116,521.20	89,016	132,734.20	101,031	128,073.60	101,684	115,920.10	99,980
Oth Plants,W/S	139,026.40	23,077	146,763.00	29,744	159,719.10	30,679	161,398.90	36,214	156,625.20	36,310
Christmas Trees, including Douglas Fir	2,048.00	18,863	2,173.80	21,529	2,222.20	22,005	2,157.60	23,352	1,989.60	23,237
Roses	6,609.40	11,071	6,166.30	12,459	6,566.00	12,563	7,429.10	14,950	7,496.80	15,199
Xmas Trees X Fir	447.7	5,083	415.3	4,534	377.8	4,100	344.5	4,105	292.4	4,342
Tree/Shrb,W/S	3,162.40	3,788	3,033.30	3,977	3,142.50	4,252	7,581.40	3,969	5,635.50	3,998
Rhododendrons, Azaleas	665.3	3,352	771.2	3,665	2,153.80	3,237	510	2,580	528.6	2,842
Unr Cut/Slps,Ns	1,675.00	802	2,290.50	987	3,860.70	1,529	612.2	240	536.5	219
Xms Tre,Doug Fir	14.7	81	21.1	90	19.2	109	11.6	110	25	121
Total	272,855.30	151,753.00	278,155.70	166,001.00	310,795.50	179,505.00	308,118.90	187,204.00	289,049.70	186,248.00

*Data compiled by Lynn Garrett, USDA APHIS CPHST Economist.

Table 4. Quantity and value of plant material exported from Europe to Canada (Quantity in 100 Kg; Value in U.S. Dollars)

	JAN.-DEC. 1999		JAN.-DEC. 2000		JAN.-DEC. 2001		JAN.-DEC. 2002		JAN.-DEC. 2003	
	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value	Quantity	Value
Unrooted Vine Cuttings And Slips	269	382,306	503	1,053,302	265	777,201	320	932,371	80	396000
Unrooted Cuttings And Slips (Excl. Vines)	543	1,871,808	753	2,918,092	873	3,701,965	814	3,955,723	727	3623108
Vine Slips, Grafted Or Rooted	517	2,060,727	329	997,308	423	1,194,108	210	854,745	342	889856.9
Trees, Shrubs And Bushes, Grafted Or Not,	462	499,046	375	304,374	300	491,301	329	384,952	609	595964.2
Rhododendrons And Azaleas, Grafted Or Not	54	25,601	54	25,117	8	12,582	11	3,190	1	3697.32
Roses (Excl. Budded Or Grafted)	173	165,924	125	161,338	149	194,832	234	628,114	45	108148.9
Budded Or Grafted Roses	311	463,917	289	470,324	241	738,104	400	1,272,015	101	353855
Live Forest Trees	-	1,324	61	359,919	141	175,510	169	274,783	187	229414.7
Outdoor Rooted Cuttings And Young Plants Of Trees, Shrubs And Bushes	385	475,901	535	661,569	538	840,606	681	919,649	437	1286823
Outdoor Trees, Shrubs And Bushes with Roots	1,823	3,139,594	1,902	3,773,154	2,267	4,195,645	2,249	3,971,311	842	1270986
Perennial Outdoor Plants	2,773	2,803,786	4,245	3,455,925	3,570	4,021,203	3,287	5,729,779	4,115	5243223
Other Live Outdoor Plants with Roots	394	184,304	548	327,427	614	244,562	1,162	698,892	256	102644.5
Indoor Rooted Cuttings And Young Plants	364	724,194	240	722,379	303	831,966	358	888,253	327	1017155
Indoor Flowering Plants With Buds Or Flowers	468	324,896	151	189,345	116	227,031	62	115,165	-	3544.2
Live Indoor Plants And Cacti	82	141,298	615	420,474	974	411,911	141	163,429	65	178288.4
Fresh Cut Roses And Buds,	:	0	1,422	1,597,510	1,543	1,778,208	1,131	1,666,266	637	929331.5
Fresh Cut Roses And Buds	260	267,734	-	0	-	0	:	0	:	0
Fresh Cut Flowers And Buds,	1,388	1,270,200	:	0	:	0	:	0	:	0
Fresh Cut Roses And Buds	218	291,044	:	0	:	0	:	0	:	0
Fresh Cut Flowers And Buds	1,742	1,668,656	:	0	:	0	:	0	:	0
Fresh Cut Flowers And Buds	:	0	5,498	5,795,329	6,925	7,713,363	6,847	7,680,387	5,254	5871904
Foliage, Branches And Other Parts Of Plants	546	571,668	567	672,987	715	812,233	701	848,059	590	716843.2
TOTAL	12,772	17,333,927	18,212	23,905,875	19,965	28,362,332	19,106	30,987,086	14,615	22820788

* Data compiled by Lynn Garrett, USDA APHIS CPHST Economist.

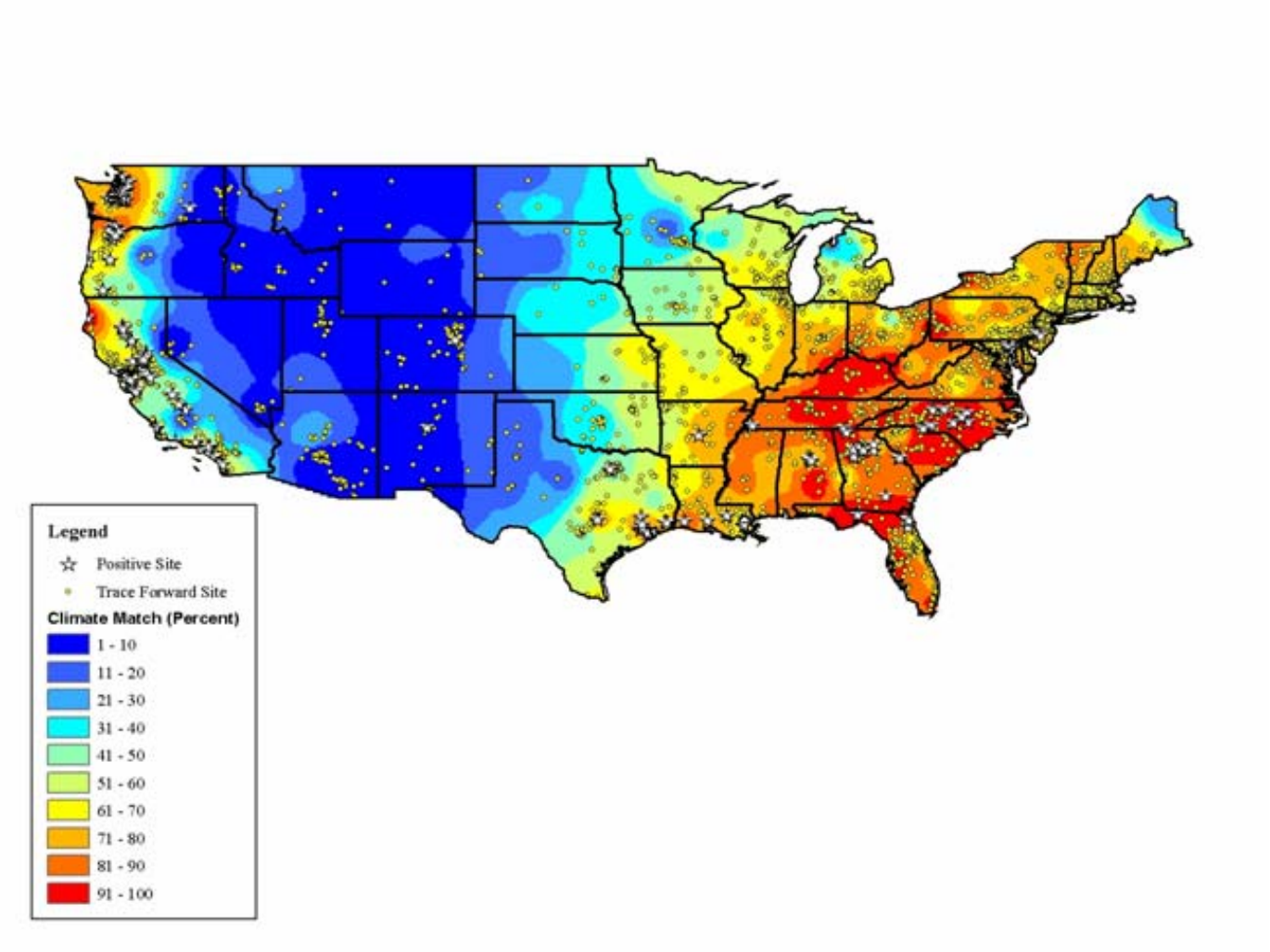

Fig. 3. Locations receiving plants shipped from nurseries testing positive for *Phytophthora ramorum* in 2004 overlaid on climate potential. Nurseries or other sites receiving *P. ramorum* infected plants are indicated with stars. Other sites are indicated with dots (Magarey *et al*., 2004).

subelement 2: Establishment and Spread Potential

Suitable hosts must be available in order to establish and sustain a pest population, and there must be a mechanism for the pest to reach these hosts. Both natural and human-assisted factors aid in the dispersal of *P. ramorum* (Davidson *et al.*, 2003a,b; Hansen *et al.*, 2002). This pathogen attacks 42 genera in 22 plant families (Table 1). Many of these hosts are widely distributed in the U.S., and conducive climatic conditions are prevalent along the east and west coasts (Fig. 3). In woody canker hosts, sporulation is not observed on the surface of cankers (Davidson *et al.*, 2003b). However, if the inner bark (cambium) is exposed and free water is present, the pathogen can sporulate on exposed surfaces, *e.g.*, the pathogen has been recovered from inner bark, wood chips (Davidson *et al.*, 2003b) and from fire wood stored for 6 months (Shelly *et al.*, 2005a). Sporulation in baiting trials was stimulated when inoculated "logs" were kept at 12°C prior to baiting (Matteo Garbelotto, pers. comm.).

subelement 3: Detection Potential

Species of *Phytophthora,* such as *P. ramorum,* are difficult to detect at the ports-of-entry, where visual inspection is the primary method of detection. This is supported by the fact that *Phytophthora* spp. have only been detected seven times since 1985 (PIN 309 database, USDA). Other pathogens and environmental conditions can elicit the same symptomology in foliar and dieback hosts. Two newly detected *Phytophthora* species, *P. nemorosa* and *P. kernoviae (*proposed name) induce similar cankers on trees and were found as a result of field analyses for *P. ramorum*. *P. nemorosa* occupies a similar ecological niche to *P. ramorum* in the U.S. (Hansen *et al.,* 2004) and *P. kernoviae* a similar niche in the U.K. (DEFRA, 2004a).

Isolation techniques including direct plating and baiting are used to detect the pathogen in plant tissues, soil and water. The efficacy of these techniques varies with season and host (Davidson *et al.*, 2002c). Molecular detection techniques include ELISA (at the genus level) AFLP, and a variety of PCR protocols. Real-time PCR methods are currently used for regulatory purposes in both the U.S. and the U.K. The ITS DNA analysis does not always distinguish *P. ramorum* from *P. lateralis*, however, multiplex methods can increase sensitivity. The possibility of failure of visual inspection to detect latent infections (plant is infected and no symptoms have developed) is a concern.

Newly established populations may go undetected for years. The disease was first noted in California in 1995 (Garbelotto *et al.,* 2001). Based on the rate of oak death, researchers suggest the pathogen was introduced at least five years before the first detection (Rizzo and Garbelotto, 2003).

The rating for Likelihood of Introduction is High. Both natural and human-assisted factors aid in the dispersal of *P. ramorum* to areas where suitable hosts and conducive climatic conditions are available to establish and sustain a population. Differences in sporulation ability and susceptibility to infection have been reported for foliar, dieback and canker hosts. The uncertainty lies with the variability in detecting *P. ramorum* and the ability to predict the levels of resistance and susceptibility among hosts and potential hosts occurring in non-infested regions.

D. PEST RISK POTENTIAL

The Consequences of Introduction and the Likelihood of Introduction are rated High; therefore, the Pest Risk Potential is High. The overall risk presented by *P. ramorum* is High due to the number of pathways associated with, and the biological uncertainties of the pathogen, *e.g.*, the demonstrated long distance dispersal in trade, long term viability of infective propagules, detection of the propagules, lack of definitive host range, the sensitivity of detection of infected plants by visual inspection, and means of natural movement. Research is needed on dormancy in chlamydospores; increased sensitivity and specificity of detection techniques; temperature requirements for survival of propagules in various sources, *e.g.*, soil, wood; risk of moving the pathogen in various species and hybrids; screening for more potential hosts including products

and propagative material of vegetable, fruit and nut crops; and natural dispersal especially animal and aerial dispersal.. Adding to the pest risk potential are the lack of a definite host range and definitive geographic distribution.

V. Pathway Assessments

The preceding section contained an overall pest risk assessment for *P. ramorum*. This section takes information from the overall assessment and focuses it on particular pathways. Pathways analyzed are **Nursery Stock (including Christmas Trees for Planting), Wood and Wood Products, Cut Christmas Trees, Cut Foliage/Flowers, Greenwaste/Compost, Potting Media and Soil.** As in the overall assessment, risk levels are categorized as "High", "Medium" and "Low", and levels of uncertainty are indicated. The risk ratings for the overall and individual pathway assessments are summarized in a comparative risk matrix (Table 5).

A. CONSEQUENCES OF INTRODUCTION

Risk Element 1: Climate/Host Interaction

This risk element considers ecological zonation and the interactions of *P. ramorum* with its hosts in a variety of environments with diverse biotic and abiotic conditions. When introduced into new areas, pests are expected to behave as they do in their native areas if the potential host plants and suitable climate are present. Broad availability of suitable climates and a wide distribution of suitable hosts are assumed to increase the impact of a pest introduction. The ratings for this risk element are based on models, research, and the number of United States Plant Hardiness Zones (USDA, 2003) which contain potential host plants and suitable climate.

Phytophthora ramorum has a high probability of encountering favorable climatic conditions throughout the ranges of potential hosts which occur in several Plant Hardiness Zones. Modeling of environmental conditions suggests there are many areas in the U.S. outside the quarantined areas of California and Oregon, which have both favorable conditions for disease development and susceptible hosts (Smith *et al.,* 2002; Magarey *et al.,* 2004; Fowler and Magarey, 2005).

The rating for the Climate/Host Interaction element is High for all pathways assessed. The uncertainty lies in the range of biotic and abiotic factors triggering establishment of *P. ramorum* in new areas.

Risk Element 2: Host Range

The risk posed by a plant pest depends on both its ability to establish a viable, reproductive population and its potential to damage plants. This risk element assumes that the consequences of pest introduction are positively correlated with the pest's host range. Aggressiveness, virulence and pathogenicity also may be factors. The consequences related to host range are

rated in accordance with the ability of the pathogen to attack a single species or multiple species within a single genus, a single plant family, or multiple families.

The host range of this pathogen continues to expand though detections in the field. APHIS currently has 31 regulated and 37 associated hosts which represent 22 plant families (Table 1). The potential host range, determined through a variety of screening techniques including detached leaf, whole plant and log assays, is also increasing (DEFRA, 2004c; Hansen *et al.,* 2005). Experimental evidence indicates that several eastern forest species would be more susceptible than western forest species such as in affected quarantined areas of California and Oregon. In addition, differences in host susceptibility are documented for forest and nursery species and may impact disease development in new environments (DEFRA, 2004c; Meshriy *et al.,* 2005; Tooley *et al.,* 2004).

Nursery Stock (including Christmas trees for planting)

Nursery plants are intended for planting in the landscape. The locations of these plantings include not only commercial plantings, private residences, arboreta, and large parks, but also interiorscapes. Christmas trees are often planted in home landscapes. *P. menziesii* var. *menziesii* and *Abies grandis* are confirmed hosts used as Christmas trees. Several nursery plants, specifically *Camellia* spp., *Rhododendron* spp., and *Viburnum* spp., have already been implicated in the movement of *P. ramorum.* These three species have been associated with repeated regulatory actions in North America and Europe and appear to present a greater risk for movement of the pathogen (APHIS, 2005c; COMTF, 2005).

Wood and Wood Products

Wood and wood products can be an important pathway for the movement of *P. ramorum.* The pathogen has been recovered from or observed to sporulate on various wood products. Sporulation has occurred on flooded chips of infected *L. densiflorus* and the flooded, cut edges of *Q. agrifolia* cankers, indicating that mulch or firewood may be infective (Davidson and Shaw, 2003). *P. ramorum* has been recovered from firewood after six months of storage (Shelly et al., 2005b). Sporulation has not been observed on the outside, intact bark of infected *Quercus* spp. or *L. densiflorus* logs (Davidson *et al.,* 2005). The main trunks of *P. menziesii* var. *menziesii* and *S. sempervirens*, important timber species, have not been found to infected by *P. ramorum* (Davidson *et al.,* 2003c) and so logs, lumber and other wood products are not regulated. Results from log inoculation tests of *P. menziesii* var. *menziesii* have been inconsistent (Hansen *et al.,* 2004).

Cut Christmas Trees

P. menziesii var. *menziesii* and *A. grandis* are grown in plantation and farmed for Christmas trees (COMTF, 2005). In mixed forests, *P. ramorum* has been found infecting understory new growth of *P. menziesii* var *menziesii* and understory small branches, needles of sprouts and twig tips of

S. sempervirens. Studies are underway to examine sporulation on these two hosts (Davidson *et al.*, 2003c). In 2004, 665 Christmas tree plantations in Oregon and 100 in Washington State were surveyed and found negative for *P. ramorum* (COMTF, 2004b). Twenty of the conifer species tested, including many of the important species that are used as Christmas trees, were susceptible to *P. ramorum* (Chastagner *et al.*, 2004). Some *Abies* spp. were highly susceptible. Symptoms included needle blight, a shoot blight resulting from needle infections, and stem lesions resulting from the growth of the pathogen from infected needles into the stem. Growth stage has an apparent significant effect on susceptibility (Chastagner *et al.*, 2004).

Cut Flowers/Foliage

Leaves and branches of hosts such as *U. californica*, *P. menziesii* var. *menziesii*, and *S. sempervirens* are used in wreaths and garlands (Davidson and Shaw, 2003). Rhododendron and bay leaves can be dried for several weeks, and after rehydration, the pathogen is still viable (Garbelotto, 2003). Numerous hosts of *P. ramorum* are popular for cut flower production, including *Acer, Camellia, Hamamelis, Kalmia, Pieris, Rhododendron, Rosa* and *Syringa* (Bachmann, 2002). There are multiple areas of uncertainty. Data are lacking on infestation and transmission rates of *P. ramorum* in other host species used for cut foliage and flowers. For example, movement of *P. ramorum* in *Viburnum* and *Rhododendron* nursery stock is documented (APHIS, 2005c,d; COMTF, 2005), but not in cut flowers. The intended uses and disposal of plants for planting and internal ornamental use differ. Cut flowers and foliage are less likely to come into contact with live hosts, since most of this material is used for decorative purposes indoors and then discarded.

Greenwaste/Compost

An estimated 10 million tons of greenwaste infected by *P. ramorum* accumulate in coastal California each year (Garbelotto, 2003). Greenwaste containing host material from infested areas may serve as a source of inoculum, especially from leaves of foliar hosts. *Rhododendron* and *U. californica* leaves can be dried for several weeks, and after rehydration, the pathogen is still infectious (Garbelotto, 2003). Although it has not been demonstrated, it is postulated that spores could be dispersed from foliar hosts via rainsplash should open transit containers be used, or that infected leaves could detach and blow away (Davidson and Shaw, 2003).

When infected wood chips, firewood and branches are kept in a cool and moist environment, they can harbor viable *P. ramorum* for long periods (Shelly *et al.*, 2005 a,b). These substrates are commonly brought into commercial composting facilities (Garbelotto, 2003).

Potting Media

Potting media are composed of organic and inorganic matter and are intended for various uses both indoor and outside. Experimental evidence indicates that *P. ramorum* may move through potting media. Parke *et al.* (2004) found *P. ramorum* moved through a sterile potting medium

and infected *Rhododendron* plants. *P. ramorum* survived in *Camellia* leaves up to 100 days in a potting medium, even after the leaves were decaying (Nina Shiskoff, pers. comm.). *P. ramorum* has also been recovered from potting medium at an infected nursery (OSOS, 2004).

Soil

Phytophthora ramorum has been isolated seasonally from soil in hiking trails and from soil on hikers' boots (Davidson *et al.,* 2002c; Tjosvold *et al.,* 2002b). In this same study, a survey of those visitors with infested shoes showed that many people leaving the park were going to other parts of California, the United States, and Europe (Tjosvold *et al.,* 2002b). Recovery rates of *P. ramorum* in areas with host plants was equal from soil samples collected on hiking trails and off the trails (Cushman and Meentemeyer, 2005). The pathogen was only recovered from samples collected from the trails in two areas without hosts suggesting human assisted movement of the pathogen along the trails.

The rating for Host Range risk element is High for Nursery Stock, Wood and Wood Products, Greenwaste/Compost, Potting Media and Soil pathways. The Cut Christmas Trees and Cut Flowers/Foliage pathways are at a lower risk because of end use and disposal and are rated Medium. There are multiple areas of uncertainty. The uncertainty for the rating for this element lies in not knowing the extent of the host range, infestation and transmission rates and disposal methods.

Risk Element 3: Dispersal Potential

Pests may disperse after introduction into new areas. The dispersal potential indicates how rapidly and widely the pests may spread within the importing country or region and is related to the pest's reproductive potential, inherent mobility, and external dispersal facilitation modes. Factors for rating the dispersal potential include: the presence of multiple generations per year or growing season, the relative number of offspring or propagules per generation, any inherent capabilities for rapid movement, the presence of natural barriers or enemies, and dissemination enhanced by wind, water, vectors, or human assistance.

The scattered pattern of sites where *P. ramorum* has become established suggests it has both natural (Hansen *et al.,* 2002; Tjosvold *et al.,* 2002c) and human assisted movement (Werres *et al.*, 2001).

Nursery Stock (Including living Christmas trees)

Phytophthora ramorum is a polycyclic pathogen on many nursery hosts; evidence indicates that inoculum production follows periods of rain and that certain foliar hosts, including *Rhododendron* and *Syringa*, are prolific producers of sporangia or chlamydospores or both (Davidson *et al.,* 2003c). Pathogen transmission has been documented from one nursery to another on nursery stock. Confirmed positive sites from the trace forward, national, and other

survey total 176 in 21 States (APHIS, 2005 c, d). While most of these were nursery finds, the total includes three residential finds. As of January 10, 2005, all nursery stock shipped from California, Oregon and Washington State are regulated to prevent movement of this pathogen (APHIS, 2005a). In Europe, *P. ramorum* was introduced to Majorca, Spain via a shipment of infected *Rhododendrons*, and many of the infections found in nurseries in the United Kingdom can be traced to plant transport from other nurseries (Davidson and Shaw, 2003).

Wood and Wood Products

Wood and wood products can be an important pathway for the movement of *P. ramorum*. The pathogen has been recovered from or observed to sporulate on various wood products. Sporulation has occurred on flooded chips of infected *L. densiflorus* and the flooded, cut edges of *Q. agrifolia* cankers (Davidson *et al.*, 2003; Davidson *et al.*, 2005). The pathogen has been recovered 3 cm into wood of *Quercus* spp. (D. Rizzo, unpublished data in Davidson and Shaw, 2003), and has been recovered from firewood after six months of storage (Shelly *et al*., 2005a) indicating that wood products (mulch, firewood, chips, etc.) may be infective. Sporulation has not been observed on the outside, intact bark of infected *Quercus* spp. or *L. densiflorus* logs (Davidson *et al*,, 2005). On the other hand, the main trunks of *P. menziesii* var. *menziesii* and *S. sempervirens*, important timber species, have not been found to infected by *P. ramorum* (Davidson *et al.*, 2003c) and so logs, lumber and other wood products are not regulated for these two species.

There is uncertainty with this pathway. Data on infestation and transmission rates of *P. ramorum* in wood products indicated the level of recovery is low, but the ability to recover is still there. When this is coupled with the unknowns in the biology of pathogen survival, especially for chlamydospores, these rates may be deceptively low.

Cut Christmas Trees

Pseudotsuga menziesii var. *menziesii*, a host of *P. ramorum*, is native to the coastal and Sierra Nevada mountains of California, Oregon, Washington and British Columbia and is grown in plantations and farmed for Christmas trees. Although not a host, *P. menziesii* var. *glauca* is native to the intermountain zones (Rocky Mountains), occurs at higher elevations, has greater cold hardiness than *P. m.* var. *menziesii*, is used for Christmas trees and has demonstrated susceptibility to *P. ramorum* in controlled studies. *P. ramorum* infects the small branches of *P. m.* var. *menziesii* and the small branches and needles of *S. sempervirens*. Studies are underway to examine sporulation on these two hosts (Davidson *et al.*, 2003c). In 2004, 665 Christmas tree plantations in Oregon and 100 in Washington State were surveyed and found negative for *P. ramorum* (COMTF, 2004b). Twenty of the conifer species tested, including many of the important species that are used as Christmas trees, were susceptible to *P. ramorum* (Chastagner *et al*., 2004, 2005). Some *Abies* spp. were highly susceptible in laboratory tests. Symptoms included needle blight, a shoot blight resulting from needle infections, and stem lesions resulting from the growth of the pathogen from infected needles into the stem. Growth stage had a significant effect on susceptibility.

Cut Flowers/Foliage

Leaves and branches of hosts such as *U. californica, P. menziesii* var. *menziesii*, and *S. sempervirens* are used in wreaths and garlands. *P. menziesii* var. *menziesii* is also farmed for Christmas trees. Some of these plants are grown within the regulated counties in California and have been sold throughout the United States. *P. ramorum* infects the small branches of P. *menziesii* var. *menziesii* and small branches and needles of *S. sempervirens*. Even without sporulation, fir wreaths and Christmas trees could serve as an infection pathway if hyphae were able to grow from infected branch tips and needles (Davidson and Shaw, 2003).

Additional host species are used for cut flowers and foliage, including *Rhododendron, Kalmia, Camellia* and *Syringa* on which *P. ramorum* can effectively produce spores (Beales *et al.,* 2004b; Davidson *et al.,* 2003c; DEFRA, 2004c; Parke *et al.,* 2002a). Though there are data for movement of *P. ramorum* in these hosts as nursery stock, there is not data for cut flowers. Though these products maybe capable of disseminating the pathogen, their intended use and disposal are principally indoors and this reduces the likelihood they will contact into contact with hosts in the new environment.

Greenwaste/Compost

Greenwaste containing host material from infested areas may serve as a source of inoculum, especially from leaves of foliar hosts (Davidson and Shaw, 2003). Even with green material dried for several weeks, some plant tissue, such as rhododendron leaves, will still sporulate upon wetting (Garbelotto, 2003). Although it has not been demonstrated, it is postulated that spores could be dispersed from foliar hosts via rain splash during transit in open containers, or that infected leaves could detach and blow away (Davidson and Shaw, 2003).

There is evidence that composting can reduce available inoculum from *P. ramorum* infected materials (Garbelotto, 2003; Aveskamp and Wingelaar, 2005), there is also evidence that composting is not equally effective on all materials (Swain *et al.*, 2005) and concerns that composted material can be re-infested with new inoculum source (Garbelotto, 2003). There are also different standards for composting, from very high standards and requirements by the California Integrated Waste Management Board to backyard efforts. The uses of composted material in landscaping and nurseries would provided a vehicle for movement of the pathogen.

Potting Media

The Oregon Department of Agriculture has detected *P. ramorum* in nursery stock, potting media containing compost and plants in a landscape in Columbia County and the Oregon Secretary of State implemented an Emergency Quarantine Order in July 1, 2004 to prevent the movement of potting media and compost (OSS, 2004).

Parke *et al.* (2005) have demonstrated the transmission of *P. ramorum* from infested potting medium to *Rhododendron* plants under greenhouse and laboratory conditions. Linderman and

Davis (2005) compared *P. ramorum* with other *Phytophthora* species in a variety of soil-less potting media (river sand, Douglas-fir bark, coir, sphagnum peat, redwood sawdust, a bark-peat-pumice potting mix), a dairy compost, and a garden soil. The pathogen was detected for six months from all substrates amended with sporangia or chlamydospores in vermiculite but not with infected leaf inoculum. *P. ramorum* sporangia survived best in peat moss, the potting mix, coir, and Douglas fir bark, and poorest in sand and soil. These results indicate that *P. ramorum* can survive very well in potting mix components or soil as culture-produced sporangia or chlamydospores.

Soil

Inoculum has been isolated seasonally from soil in hiking trails and from soil on hikers' boots (Davidson *et al.,* 2002c; Tjosvold *et al.,* 2002b). In this same study, a survey of those visitors with infected shoes showed that many people leaving the park were going to other parts of California, the United States, and Europe (Tjosvold *et al.,* 2002b). The concern for soil and litter movement by equipment has prompted California authorities to request that vehicles and other equipment including tents and shoes leaving an established area be washed to remove soil before leaving the area. *P. ramorum* has been recovered, albeit at low levels, from a variety of unprocessed and processed wood products (Shelly *et al.*, 2005b). Soil on felled trees or logging equipment from infested forests may also contain spores (Davidson and Shaw, 2003). Recovery rates of *P. ramorum* in areas with host plants was equal from soil samples collected on hiking trails and off the trails. The pathogen was only recovered from samples collected from the trails in two areas without hosts suggesting human assisted movement of the pathogen along the trails (Cushman and Meentemeyer, 2005). Fitchner *et al.* (2005) reported that it is difficult to detect chlamydospores using current baiting methods, and indicates an underestimation of the amount of inoculum present in the soil.

The rating for the Dispersal Potential element is High for the Nursery Stock, Wood and Wood Products, Greenwaste/Compost, Potting Media and Soil pathways. The risk for Cut Foliage/Flowers and Cut Christmas Trees is Medium because of intended use, *i.e.*, indoors. However the uncertainty is the final disposition, which could be indoors in trash, or outside in compost or greenwaste.

Risk Element 4: Economic Impact

Introduced pests cause a variety of direct and indirect economic impacts, such as reduced yield, reduced commodity value, loss of foreign or domestic markets, and non-crop impacts. Factors considered during the ranking process included: effect on yield or commodity quality, plant mortality, ability to act as a disease vector, increased costs of production including pest control costs, lower market prices, effects on market availability, increased research or extension costs, or reduction in recreational land use or aesthetic value, oorganism attacks hosts or products with significant commercial value, organism directly causes tree mortality or predisposes host to mortality by other organisms, damage by organism causes a decrease in value of the host affected, for instance, by lowering its market price, increasing cost of production, maintenance,

or mitigation, or reducing value of property where it is located, and lack of effective control measures.

Tourism can also be impacted. Visitors to parks and forests are impacted because access to selected areas is restricted during certain seasons to prevent movement of the pathogen, or to protect visitors from falling limbs from trees dead because of the disease. When visitors are requested or required to take precautions to prevent movement of the pathogen, park and forest staff maybe required to provide educational information, staff cleaning areas, and provide appropriate supplies and equipment to remove soil from shoes and vehicles.

Nursery Stock (Including living Christmas trees and all Propagative Material).

Nursery crops are woody perennial plants, such as ornamental trees, shrubs, and vines, that are primarily used for landscaping. The 2003 U.S. domestic production nursery crops were valued about $9.2 billion. Imports for these crops were $483 million and exports were $210 million (Jerado, 2004). The presence of *P. ramorum* has resulted in restrictions in foreign and domestic trade. Canada, Korea, Australia, New Zealand, and the European Union have placed restrictions on the movement of affected plant and plant parts from the U.S. (Jonathan Jones, pers. comm.; Rizzo and Garbelotto, 2003). The U.S. has placed restrictions on movement of host materials for propagation from the European Union.

Wood and Wood Products

Thousands of *Quercus* and *L. densiflorus* trees have died following infection by this pathogen, requiring expensive removal in certain settings, more intensive fire management in others, and limited access to parts of parks and forests (COMTF**,** 2004). Economic losses from removal of infected *Quercus* and *Lithocarpus* trees may be partially offset by utilization of the material for wood products, but these materials are limited to use within quarantine areas or require a special permit limiting use which the California Department of Agriculture may determine appropriate to issue. No such limited permits are yet permitted for interstate movement under Federal regulation, though this has been under consideration. The presence of *P. ramorum* has resulted in restrictions in foreign and domestic trade. Canada, Korea, Australia, New Zealand, and the European Union have placed restrictions on the movement of affected plant and plant parts from the U.S. (Jonathan Jones, pers. comm.; Rizzo and Garbelotto, 2003). Should *P. ramorum* become established in other hardwood forests of the U.S., the potential economic threat to commercial timber production exceeds $30 billion (Kliejunas, 2003).

Cut Christmas Trees

The U.S. cut Christmas tree industry had a wholesale value of $520 million in 2003 (NASS, 2004). Oregon leads with a total production of $158 million (NASS, 2004) and with markets through the U.S., Canada and Mexico (OASS, 2004). Washington State and California follow with values of 60 and 10.4 million dollars, respectively. A major Christmas tree species, *P.*

menziesii var. *menziesii,* is a host of *P. ramorum*. Chastagner *et al.* (2004) found other important species susceptible in laboratory trials.

Cut Flowers/Foliage

U.S. production exceeded $424 and $662 million respectively for cut flower and foliage sales (NASS, 2004). Many of the species surveyed and listed by National Agricultural Statistics Service (NASS) were not hosts of *P. ramorum,* but there is an increase in flower production from woody ornamentals and many of these plants are hosts for the pathogen, including *Acer, Camellia, Hamamelis, Kalmia, Pieris, Rhododendron, Rosa* and *Syringa* (Bachmann, 2002).

Greenwaste/Compost

A major economic issue for quarantined counties in California is appropriate disposal of *P. ramorum*-infected or contaminated greenwaste. It is estimated that about 10 million tons of infected greenwaste are accumulating in quarantined counties in California per year (Garbelotto, 2003). This is complicated by the fact that only 50% of this material can go into landfills (COMTF, 2005).

Twenty-nine of 143 nurseries questioned through State officials or Industry representatives in the quarantined counties of California indicated they would have a financial loss if they could no longer use native soil or local compost (Sandy Jordan, pers. comm.).

Potting Media

The pathogen was detected in potting media at a infested nursery in Oregon (OSOS, 2005). Subsequently, Oregon requires potting media used at certified nurseries to be tested. There is experimental evidence that river sand, Douglas-fir bark, coir, sphagnum peat, redwood sawdust, and a bark-peat-pumice potting mix are capable of harboring *P. ramorum* (Linderman and Davis, 2005).

Soil.

Twenty-nine of 143 nurseries questioned through State officials or Industry representatives in the quarantined counties of California indicated they would have a financial impact if they could no longer use native soil or local compost (Sandy Jordan, pers. comm.).

The Economic Impact rating for all pathways is rated High. Uncertainty stems from unknowns regarding the extent of the host range, the restricted movement imposed by the quarantines, and the value of these products on the open market.

Risk Element 5: Environmental Impact.

The ratings for this risk element are based on three aspects: the potential of the pest to disrupt native ecosystems and habitats exhibited within its current geographic range; the need for additional chemical or biological control programs due to the presence of the pest; and the potential of the pest to directly or indirectly impact species listed as Threatened or Endangered (50 CFR § 17.11-12). When a pest is known to infest or infect other species within the same genus, and host specificity data does not exist with the listed plant, then the listed plant is assumed to be a potential host.

In forests, more than 20 non-indigenous species of plant pathogens attack woody plants (Liebhold *et al*. 1995). Two of the most destructive plant pathogens are *Cryphonectria parasitica*, and *Ophiostoma ulmi*, the causal agents of chestnut blight and Dutch elm disease, respectively. Before the introduction of chestnut blight, approximately 25% of eastern U.S. deciduous forest consisted of American chestnut (*Castanea dentata*) trees (Liebhold *et al.*, 1995). These trees have all but disappeared. In urban and forest environments, species and cultivars of *Ulmus* have been destroyed by *O. ulmi*. Losses in real estate value and costs of removal and disease management are estimated to be about $100 million/year (Stipes and Campana, 1981). In addition, plant pathogens of forest plants cause the loss of approximately 9%, or $7 billion, of forest products each year (Hall and Moody, 1994; USBC 1998). The proportion of introduced plant pathogens in forests is similar to that of introduced insects (about 30%), thus, approximately $2.1 billion in forest products are lost each year to non-indigenous plant pathogens in the United States. In addition to the direct costs of the prevention, eradication or suppression of this pathogen, the economic costs must also include indirect ecological consequences (changes in locally important, ecological services such as perturbations of hydrological cycles, *e.g.*, flood control and water supply; waste assimilation; nutrient recycling, conservation and regeneration of soils; crop pollination, *etc.*) and must address both current-use value and future-use values.

Quercus species are the most important and widespread of the hardwood trees in the North Temperate Zone (Pavlik *et al.*, 1991, as cited in Kliejunas, 2002). These woodlands yield important benefits, *e.g.*, water and watershed protection, grazing, wildlife food and habitat, recreation, and wood products (Thomas, 1997), are known for their scenic beauty, contribute to tourism and high property values and are valued for shelter and food for wildlife. The loss of keystone *Quercus* species in these forests would be detrimental to forest health. In addition, the effects on rare and endangered plant species in these regions are unknown. *Phytophthora ramorum* has the potential to cause significant environmental effects such as ecological disruption or reduction of biodiversity, especially in eastern hardwood forests. This pathogen has already caused environmental damage with the death of *Quercus* and *Lithocarpus* trees in California. The effect of the loss of these trees on animal populations and the risk from fire hazard are being researched. Data exist that bird populations are affected with a change in species densities, but the total impact is unknown.

A number of genera on the APHIS Hosts and Associated Plants list have species on the U.S. Fish and Wildlife Services Threatened and Endangered Species list. These are *Rhododendron*

chapmanii , Quercus hinckleyi, Arctostaphylos confertiflora, A. glandulosa ssp. crassifolia, A. hookeri var. *ravenii, A. morroensis, A. myrtifolia*, and *A. pallida*.

It has been documented that *P. ramorum* can move in Nursery Stock (APHIS, 2005), in Wood and Wood Products (Shelly *et al.*, 2005b), Cut Christmas Trees (Chastagner *et al*., 2004), Cut Flowers/Foliage (Davidson *et al.*, 2003c; DEFRA, 2004c; Parke *et al.*, 2002a), Greenwaste/Compost (Garbelotto, 2003; Swain *et al.*, 2005), Potting Media (Linderman and Davis, 2005; Parke *et al.*, 2005), and Soil (Davidson *et al.*, 2002c; Davidson and Shaw, 2003; Tjosvold *et al.*, 2002b). All of the pathways present a potential risk to contaminating the environment with *P. ramorum*.

The Environmental Impact rating for all pathways is High. The uncertainty lies with the difficulty in producing estimates for the costs of *P. ramorum* that address all of the relevant ecological components. These include: (1) the direct costs of prevention, eradication or suppression; (2) the economic costs, *e.g.* current-use-and future-use values, *etc*., and (3) the indirect ecological consequences (changes in locally important ecological processes such as perturbations of hydrological cycles, *e.g.*, flood control and water supply, waste assimilation, nutrient recycling, conservation and regeneration of soils, and crop pollination).

B. LIKELIHOOD OF INTRODUCTION TO NEW AREAS IN U.S.

Risk Element 6: Pest Opportunity (Survival and Access to Suitable Habitat and Hosts)

subelement 1: Entry Potential

The rating for this risk element is based on the volume and value of domestic shipments and of imports from Europe and Canada. It is also based on the likelihood that the pathogen will survive post harvest treatments and shipping conditions. Live plants are grown, shipped and sent to areas conducive to their survival. Plant products, such as cut flowers and foliage may also be treated in ways not detrimental to the survival of *P. ramorum*. Other infested plant products, such as logs, lumber, wood chips and firewood, though not handled as gently as live plants and cut flowers/foliage, still harbor the pathogen and present a pathway for introduction into new areas. Living plants are not likely to receive postharvest treatments such as irradiation, methyl bromide, or steam sterilization because there is no "harvest" of the commodity, and the types of treatments that would kill pests are also likely to kill the plants. In addition, the presence of potting media requires specific testing to ensure the efficacy of any proposed post-harvest treatments (Jarvis, 1992). General transport conditions for potted plants range from 10°-18°C and 85-90 RH (McGregor, 1987).

Nursery stock (Including living Christmas trees).

One or more stages of *P. ramorum* are likely to survive in the plant host during transportation. This was demonstrated recently when infected nursery stock in 21 States was traced to infested

nurseries in California. In Europe, *P. ramorum* was introduced to Majorca, Spain via a shipment of infected rhododendrons, and many of the infections found in nurseries in the United Kingdom could be traced to plant transport from other nurseries (Davidson and Shaw, 2003). Chlamydospores are often formed inside host tissue (Pogoda and Werres, 2004; Parke *et al.*, 2003), and are unlikely to be dislodged during standard harvesting, handling and shipping operations. *P. ramorum* has survived over 100 days in greenhouse conditions (Shishkoff, 2004), overwintered in the UK (DEFRA, 2004c), and oversummered in the U.S. (Fitchner *et al.*, 2005). Much of the biology of chlamydospores of *P. ramorum* is still under investigation, but chlamydospores for other *Phytophthora* species can survive for up to 5 years (Erwin and Ribeiro, 1996). Detached *Rhododendron* and *U. californica* leaves still produced sporangia several weeks after drying (Garbelotto, 2003). In addition to movement with the aerial portions of the host, there is laboratory evidence that the pathogen may move in potting medium and evidence of root infection in nursery stock (Parke *et al.*, 2004).

Wood and Wood Products, Cut Christmas Trees, Cut Flower/Foliage

This pathogen has been detected and isolated from bark, cambium and xylem, is usually limited to a depth of 3 cm in *Quercus* and *L. densiflorus*, but has been detected as deep as 18 cm (Hansen *et al*, 2002). Chlamydospores are often formed inside host tissue (Pogoda and Werres, 2004; Parke *et al.*, 2003), and are unlikely to be dislodged during standard harvesting, handling and shipping operations. *P. ramorum* has survived over 100 days in greenhouse conditions (Shishkoff, 2004), overwintered in the UK (DEFRA, 2004c), and oversummered in the U.S. (Fitchner *et al.*, 2005). Much of the biology of chlamydospores of *P. ramorum* is still under investigation, but chlamydospores for other *Phytophthora* species can survive for up to 5 years (Erwin and Ribeiro, 1996).

Greenwaste/Compost, **Soil, Potting Media**

P. ramorum has been detected from greenwaste (Shelly *et al.*, 2005), compost (Garbelotto, 2003), soil (Tjosvold *et al.*, 2002b) and potting media (Parke *et al.*, 2005). Spores of *P. ramorum* have been detected on the shoes of hikers and on the tires of mountain bikes and vehicles used on dirt roads or trails in California (Tjosvold *et al.*, 2002b). Linderman and Davis (2005) compared *P. ramorum* with other *Phytophthora* species in a variety of media (river sand, Douglas-fir bark, coir, sphagnum peat, redwood sawdust, a bark-peat-pumice potting mix, a dairy compost, and a garden soil) and found that the pathogen was detected for six months from all substrates.

The risk rating for the Entry Potential subelement is High for all pathways. Uncertainty factors include lack of data on infection and pathogen and survival rates for most products, especially cut flowers and foliage, long term survival in greenwaste, compost, potting media and soil; and propagules present in wood and wood products.

subelement 2: Establishment and Spread Potential

Phytophthora ramorum is a polycyclic pathogen; evidence indicates that inoculum production follows periods of abundant rainfall and *P. ramorum* produces large numbers of sporangia, chlamydospores or both on certain foliar hosts (Davidson *et al*, 2003). *P. ramorum* has an optimum temperature range between 18-25 °C (Werres *et al.,* 2001; DEFRA, 2004c) and survives temperatures as low as -9°C (DEFRA, 2004c). Suitable hosts must be available to establish and sustain a pest population, and there must be a mechanism for the pathogen to reach these hosts. Both natural and human-assisted factors aid in the dispersal of *P. ramorum* (Davidson *et al.,* 2003a,b; Hansen *et al.*, 2002). This pathogen attacks 42 genera in 22 plant families (Table 1) and this range may continue to expand (Brasier *et al.,* 2002; Hansen *et al.*, 2005; Tooley and Kyde, 2003; Tooley *et al.*, 2004). Many of these hosts are widely distributed in the U.S., and conducive climatic conditions are prevalent along the east and west coasts. Modeling of environmental conditions suggests there are several areas in the U.S. outside of quarantined zones that have both favorable conditions for disease development and susceptible hosts (Magarey *et al.*, 2004; Fowler and Magarey, 2005).

The pathogen is established in forests in fourteen counties in California and one county in Oregon (APHIS, 2005d). Pathogen has been detected in nursery stock in many countries in the EU, and from limited established plantings of *Rhododendron* and tree hosts in Europe (COMTF, 2004; DEFRA, 2004b; EPPO, 2004). Newly established populations in forest or other natural environs may go undetected for many years owing to their cryptic nature, concealed activity, slow development of damage symptoms, or misdiagnosis (Rizzo *et al.*, 2002b). This suggests that the pathogen can be present and become established before the disease is detected. Eradication is currently not feasible for certain forest situations, but is being attempted in one Curry County, Oregon. Three years after initial eradication efforts, *P. ramorum* is still being found in native soil and streams in Curry County, Oregon (Kanaskie *et al.,* 2004). Although eradication was not considered feasible, suppression efforts are underway in Humboldt County, California (COMTF, 2005).

Nursery Stock (Including living Christmas trees).

Many of the hosts on the regulated and associated host lists are major nursery species and or major forest/understory species. There is contiguous distribution of hosts, potential hosts and favorable conditions along the east and west coasts (Magarey *et al.,* 2004). *P. ramorum* has been detected and eradicated in nursery stock shipped from California to 21 other States. This pathogen has also been detected in nursery stock in many EU Countries, and from a few established plantings on *Rhododendron* and various tree hosts (EPPO, 2004). In addition, in infested nurseries, soil or mulch in the pots of rhododendron plants, other host plants, and even unsusceptible plants may contain spores of *P. ramorum* although the plants appear healthy (Davidson and Shaw, 2003). *P. ramorum* has been also isolated from irrigation water from an infested rhododendron nursery (Tjosvold *et al.,* 2002c).

Wood and Wood Products.

P. ramorum has been recovered from inner bark and wood chips (Davidson *et al.,* 2003b) suggesting that when the inner bark is exposed, as in the debarking process, and free water is present, the pathogen can sporulate on the exposed surfaces. Sporulation was stimulated in baiting trials when inoculated "logs" were kept at 12°C prior to baiting (Matteo Garbelotto, pers. comm.) and has been recovered from fire wood stored for 6 months (Shelly *et al.*, 2005a).

Cut Foliage/Flowers and Cut Christmas Trees

P. ramorum readily sporulates from *U. californica* leaves under moist, temperate conditions. In addition, chlamydospores are formed in and on bay leaves. *P. ramorum* infects the small branches of *P. menziesii* var. *menziesii* and small branches and needles of *S. sempervirens*. In 2004, 665 Christmas tree plantations in Oregon and 100 in Washington State were surveyed and found negative for *P. ramorum* (COMTF, 2004b). Twenty of the conifer species tested, including many of the important species that are used as Christmas trees, were susceptible to *P. ramorum* (Chastagner *et al*., 2004). Cut flowers and foliage are less likely to come into contact with live hosts.

Greenwaste/Compost/Potting Media

P. ramorum has been detected from greenwaste (Shelly *et al.*, 2005), compost (Garbelotto, 2003), and potting media (Parke *et al.,* 2005). Greenwaste containing host material from infested areas may serve as a source of spores, especially from leaves of foliar hosts (Davidson and Shaw, 2003). Even with green material dried for several weeks, some plant tissue, such as rhododendron leaves, will still sporulate upon wetting (Garbelotto, 2003). Although it has not been demonstrated, it is likely that spores could be dispersed from foliar hosts via rainsplash during transit in open containers, or that infected leaves could detach and blow away (Davidson and Shaw, 2003). Linderman and Davis (2005) compared the survival of *P. ramorum* with other *Phytophthora* species in a variety of media (river sand, Douglas-fir bark, coir, sphagnum peat, redwood sawdust, a bark-peat-pumice potting mix, a dairy compost, and a garden soil) and found that the pathogen was recovered from all substrates for six months.

Soil

Recovery rates of *P. ramorum* in areas with host plants was equal from soil samples collected on hiking trails and off the trails. The pathogen was only recovered from samples collected from the trails in two areas without hosts suggesting human-assisted movement of the pathogen along the trails (Cushman and Meentemeyer, 2005). Fitchner *et al.* (2005) indicate current baiting techniques can underestimate the amount of inoculum present in the soil.

The risk rating for the Spread and Establishment subelement is High for Nursery Stock, Wood and Wood Products, Greenwaste, Compost, Potting Media and Soil. The risk is lower for Cut Christmas Trees because the negative detections in nursery surveys, and for Cut Flowers/Foliage because of intended use, but the uncertainty stems from the fact that species used for Christmas trees and Cut Flowers and Foliage are susceptible.

subelement 3: Detection Potential

Species of *Phytophthora*, such as *P. ramorum*, are difficult to detect at the ports–of-entry, where visual inspection is the primary method of detection. This is supported by the fact that *Phytophthora* spp. have only been detected seven times since 1985 (PIN 309 database, USDA). Other pathogens and environmental conditions can elicit the same symptomology in foliar and dieback hosts. Two new *Phytophthora* species, *P. nemorosa* and *P. kernoviae (*proposed name) induce similar cankers on trees and were found as a result of field analyses for *P. ramorum*. *P. nemorosa* occupies a similar ecological niche to *P. ramorum* in the U.S. (Hansen *et al.*, 2004) and *P. kernoviae* a similar niche in the U.K. (DEFRA, 2004d). Eradication efforts at nurseries and in forests are not always successful. Soil still harbored *P. ramorum* three years after initial eradication efforts in Curry County, Oregon (Hansen *et al.*, 2005), and *P. ramorum* resurfaced at nurseries in U.S. and U.K. even after prescribed control measures have been completed (APHIS, 2005c; DEFRA, 2005b).

Isolation techniques including direct plating and baiting are used to detect the pathogen in plant tissues, soil and water. The efficacy of these techniques varies with season and host (Davidson *et al.*, 2002c). Molecular detection techniques include ELISA (at the genus level), AFLP, and a variety of PCR protocols. A real-time PCR method is currently being used for regulatory purposes in both the U.S. and the U.K. The ITS DNA analysis does not always distinguish *P. ramorum* from *P. lateralis*, however, multiplex methods can increase sensitivity. The possibility of latent infections (plant is infected but and no symptoms have developed) is a concern.

Newly established populations may go undetected for years. The disease was first noted in California in 1995 (Garbelotto *et al.*, 2001). With rate of oak death, researchers suggest the pathogen was introduced at least five years before the first detection (Rizzo and Garbelotto, 2003).

Nursery stock (including living Christmas trees), Cut Foliage/Flowers, Cut Christmas Trees

Visual diagnosis is still the first step in detection of *P. ramorum* and can be complicated by other factors. For example, environmental conditions and other pathogens produce the similar symptoms (Davidson *et al.*, 2003b) and fungicides commonly used to control other *Phytophthora* species on rhododendron may mask symptoms of *P. ramorum* (Davidson and Shaw, 2003). In addition, in infested nurseries, soil or mulch in the pots of rhododendron plants, other host plants, and even unsusceptible plants may contain spores of *P. ramorum* although the plants appear healthy (Davidson and Shaw, 2003), and may be a source for reinfestation (DEFRA, 2005b).

Chastagner *et al.* (2005) reported that the application of contact fungicides in laboratory trials did not limit the recovery of *P. ramorum* from inoculated conifer hosts, although growth was slower.

Wood and Wood Products

Detection methods for assessing wood products present unique challenges. Direct isolation on a semi-selective medium or baiting with pear fruit have been used to recover the pathogen from symptomatic wood and bark. The efficacy of these methods depends on the host and time of year. Isolation frequencies from wood tend to be lower than from other plant parts. Recovery was increased by taking plates of the semi-selective medium (PARP) to the field; however, 60% of the samples were negative (Storer *et al.*, 2002). The pathogen could not be isolated from wood chips after air drying for two weeks (Swain *et al.*, 2002), but lack of isolation is not definitive evidence that the pathogen is devitalized. The most sensitive detection method, PCR, detects the presence of the DNA, but it does not indicate the viability of the pathogen.

Greenwaste/Compost, Soil and Potting Media

Fichtner *et al.* (2005) indicated that current baiting techniques are adequate to detect sporangia but not chlamydospores in soil and thereby underestimate the amount of inoculum present. The same baiting techniques are used to recover *P. ramorum* from greenwaste, compost and potting media.

The risk rating for Detection Potential subelement is High for all pathways. The sensitivity and specificity of these methods vary with season, host, host part, and pathogen propagule.

C. PEST RISK POTENTIAL

The overall risk presented by *P. ramorum* is High due to the number of pathways moving the pathogen and the associated uncertainties, *e.g.*, long term viability of infective propagules, detection of the propagules, lack of definitive host range, and means of natural movement. Research is needed on: (1) factors inducing and breaking dormancy in chlamydospores, which is needed to develop effective detection protocols and mitigation measures; (2) increased sensitivity and specificity of detection techniques; (3) temperature requirements for survival of propagules in various sources, *e.g.*, soil, wood; (4) risk of moving the pathogen in various species and hybrids of plants for planting, Christmas trees (cut and uncut), cut flowers and cut foliage; (5) screening for more potential hosts including products and propagative material of vegetable, fruit and nut crops; (6) natural dispersal especially animal and aerial dispersal; and (7) the actual geographic distribution of *Phytophthora ramorum*.

Table 5. *Phytophthora ramorum* Comparative Risk Matrix for an organism assessment and for selected, unmitigated pathway assessments. Risk rating levels are "High", "Medium" and "Low".

Risk Element /subelement	Organism Assessment	Pathways						
		Nursery stock	Wood/Wood Products	Cut Christmas Trees	Cut Flowers/ Foliage	Greenwaste/ Compost	Potting Media	Soil
Consequences of Introduction								
Climate/Host Interaction	High	High	High	High	High	High	High	High
Host Range	High	High	High	Medium	Medium	High	High	High
Dispersal Potential	High	High	High	Medium	Medium	High	High	High
Economic	High	High	High	High	High	High	High	High
Environment	High	High	High	High	High	High	High	High
Likelihood of Introduction								
Pest Opportunity Entry Potential	High	High	High	High	High	High	High	High
Spread/Establishment	High	High	High	Medium	Medium	High	High	High
Detection Potential	High	High	High	High	High	High	High	High
Risk Potential	**High**	**High**	**High**	**High**	**High**	**High**	**High**	**High**

VI. MITIGATION MEASURES

A. INTRODUCTION

The risks associated with the importation and domestic movement of hosts and products from hosts of *Phytophthora ramorum* from infested areas without specified growing, inspection, and certification requirements were analyzed to be High. A risk potential of High necessitates the implementation of appropriate mitigation measures.

Traditional regulatory mitigation programs for plant pathogens have three components: 1) exclusion; 2) containment, suppression, and eradication; and 3) assistance to exporters (Kahn, 1991). Were specific efficacies were not known for *P. ramorum*, they were deduced through consultations with experts based on the behavior of other *Phytophthora* spp. Diagrams for the foliar host (Fig.4), canker host (Fig.5), soil (Fig.6) and dormancy phase (Fig.7) include points were mitigation measures may be applied. Rizzo *et al.* (2005) reviewed available research and suggested management options.

Exclusion

Exclusion of *P. ramorum* will require large geographic barriers. The caducous sporangia and zoospores are easily dispersed, locally, in rain events, and have been postulated to move long distances by significant weather events (Hansen *et al.*, 2002). Sporangia of *Phytophthora*, i.e. *P. infestans* do not survive long distance dispersal because viability is decreased under dry conditions (Ristaino and Gumpertz, 2000).

Exclusion of the A1 mating type from Europe is possible by prohibiting the entry of living plant hosts and untreated plant-derived products, compost and potting media. Based on the general biology of heterothallic *Phytophthora* species, more virulent strains can result from genetic recombination (Erwin and Ribeiro, 1996), *e.g., P. infestans* (Smart and Fry, 2001). One incident of the introduction of a European-type isolate of *P. ramorum* has already occurred in North American and there is evidence that this isolate is more aggressive than the North American isolates (Garbelotto *et al*., 2004; Parke *et al.,* 2004). Exclusion of A2 mating type is possible by prohibiting movement of all hosts (providing all hosts have been identified) from infested areas. Mitigation of the risk is possible by prohibiting movement of the highest risk hosts, *i.e.*, prohibiting movement of those plants or plant genera which have not only been detected with the disease-causing organism, but those types of plants repeatedly found with *P. ramorum*.

Containment

Under current Federal domestic regulations (7 CFR §301.92), nurseries in the quarantined areas must be inspected, sampled and tested annually for symptoms of *P. ramorum.* In addition, pre-shipment inspections are required prior to interstate movement. The Emergency Federal Order Restricting Movement of Nursery Stock From California, Oregon, and Washington Nurseries (Dec. 21, 2004) and 7 CFR § 301.92, also require nurseries in quarantine areas of California, Oregon and Washington State to have annual and pre-shipment inspections of host materials prior to interstate shipment. If the pathogen is detected during any inspection process, eradication efforts are initiated.

Suppression

Suppression efforts for *P. ramorum* in nursery stock have focused on national surveys and the development of best management practices for nurseries (APHIS, 2005e). Suppressive mitigation measures used for other *Phytophthora* species include sanitation, disinfectants, fungicides, fumigants, methods of water treatment and distribution, and type and form of bed beneath the pots (Erwin and Ribeiro, 1996; Hartmann *et al.,* 2002).

Suppression efforts for *P. ramorum* in forests in the quarantined counties of California have focused on educational outreach, the seasonal closure of trails (COMTF, 2005), and facilities for soil removal from shoes (Davidson *et al.,* 2005) and bicycle tires (Tjosvold *et al.,* 2005). In Humboldt County, California, efforts to reduce inoculum load by removing infected trees have been initiated (COMTF, 2004c).

Eradication

Removal and destruction of plant material and related articles are the major eradication efforts for *P. ramorum* in nurseries and forests. The only current effort to eradicate *P. ramorum* from a forest setting is underway in Curry County, Oregon (Goheen *et al.,* 2002a). The recent detection

of *P. ramorum* in soil three years after host eradication (Kanaskie *et al.*, 2004), coupled with research evidence that *P. ramorum* has a soil phase (Parke *et al.*, 2004, 2005; Nina Shishkoff, pers. comm.; Fichtner *et al.,* 2004, 2005), suggests that additional eradication measures may be needed.

Sanitation

Sanitation during and after propagation is necessary to maintain pathogen free material (Erwin and Ribeiro, 1996: from Pegg, 1978 and E.M. Hansen, 1970). For control of a polycyclic foliar pathogen, such as *P. ramorum*, in the field, sanitation needs to be 99.9% effective (Vanderplank, 1963, as cited in Erwin and Ribeiro, 1996). Sanitation practices should include removing and testing of symptomatic stock, sterilization of potting media, and disinfection of tools, benches, workers shoes and gloves and other equipment. All symptomatic material or diseased plants should be disposed in a sanitary landfill or otherwise treated to prevent the spread of *P. ramorum*.

Garbelotto *et al.* (2003) found that 9-12 hours of leaf wetness at 18°to 22°C are necessary to obtain significant infections on *U. californica* leaves. Contaminated irrigation and contaminated recycled water disperses *Phytophthora* propagules, either directly by delivering contaminated water, or indirectly by splashing inoculum from plant and ground surfaces to other plants (Erwin and Ribeiro, 1996). Multiple methods to disinfest water are available and include chlorine products, filters and ozonation (Hartman *et al.,* 2002). Water treatment should be coupled with testing before and after treatment. The recycling of irrigation water has been adopted for environmental reasons, but this process increases the risk of spreading the pathogen.

Chemical control would include fungicides and disinfectants for benches, tools and equipment. Sodium hypochlorite is a commonly used source of chlorine that is great for these surfaces, but can be phytotoxic (Hartmann *et al.,* 2002). Pesticides are available and registered for use with *Phytophthora* species (Table 6), but these products are fungistatic and not fungicidal.

A series of best management practices based on epidemiological factors could include multiple mitigations such as pathogen free propagating material (stock plants) or seed, a pathogen free water source, clean potting media, pots, a strict sanitation protocol including cleaning and testing of benches and beds, cleaning of tools and equipment, and sanitation measures for staff shoes, hands, *etc*. The Nursery Committee of the COMTF developed best management practices (Suslow *et al*., 2004).

The State of Oregon responded to the detection of sudden oak death by the establishment of regulations in 2001 prohibiting the entry of products of susceptible oaks from California unless they have been kiln-dried or heat-treated to 71.1°C for 75 minutes measured at the core (ODA, 2001). Oregon required that soil associated with oak commodities be sterilized by dry heat at 110°C for 16 hours (ODA, 2001). After the quarantine was enacted in Oregon, the pathogen was detected at several sites in Curry County: all infected plants are being burned on site. The eradication efforts in Curry County are cooperative among State and Federal agriculture and forestry agencies.

B. NURSERY STOCK, CHRISTMAS TREES, and CUT FOLIAGE/FLOWERS

Chemical treatment

Linderman *et al*. (2005) evaluated fungicides labeled for use on Phytophthora diseases on several *Phytophthora* species (*P. cactorum, P. citricola, P. nicotiana, P. citrophthora* and *P. ramorum).* Systemic and translaminar fungicides were effective in disease suppression but were not effective as eradicants. Of all fungicides tested, menfenoxam was most effective on all of the species tested, with the exception of *P. citrophthora*.

Tjosvold *et al.* (2005) also evaluated registered products on *Rhododendron, Camellia*, *Pieris* and *Viburnum.* Those products most effacious on *Rhododendron* were selected for timing of application studies. Maximum rates of mefenoxam (metalaxyl-M), dimethomorf, pyraclostrobin and fenamidone were applied as foliar sprays on wounded and non-wounded leaves. Preventative activity was observed for two weeks but not for four weeks. Post infection treatments were ineffective. Only dimethomorf significantly reduced the success of isolation recovery from lesions. Metalaxyl –M, azoxystrobin and fenamidone/mancozeb completely inhibited symptom development on *Rhododendron* spp. (Turner *et al.*, 2005). Heungenis *et al.* (2005) tested the efficacy of metalaxyl, dimethomorf, cyazofanid, fosphetal Al, cymoxanil and mancozeb to control *P. ramorum* on *Rhododendron*. Metalaxyl, dimethomorf and cyazofanid were the most effective, fosphetal Al and cymoxanil were intermediate, and least effective was mancozeb. The best control was achieved when the lower surface of leaf was covered with the fungicide. Fungicides were better as "protectants" and not effective as "curatives" (Heungenis *et al.*, 2005).

Chastagner *et al.* (2005a) evaluated 20 systemic and contact fungicides on seedlings of *Pseudotsuga menziesii* var. *menziesii*. A drench application of mefenoxam, prior to bud-break, prevented infection and post-bud break applications of mancozeb, maneb, and metiram provided 100 % control. Variable results were obtained with other fungicides. The surfactant, Latron CS-7, applied at post bud break yielded 60-100% reduction in infection. A concern associated with the potential use of fungicides to control this disease is the possibility that fungicides might suppress symptom development on infected plants. Systemic fungicides might have the potential to suppress symptom development, but this is not likely with the contact types of fungicides found to be effective in protecting seedlings from *P. ramorum* Chastagner *et al.* (2005a).

Dimethomorph and phosphate were applied to *Vaccinium ovatum, Lithocarpus densiflorus, Rhododendron macrophyllum* and *Umbellularia. californica* in the field at 1 and 2x recommended rates. Detached leaves were taken to the laboratory for wound inoculation assays. No treatment provided complete protection (Goheen *et al.*, 2005).

Biological control

Bacillus brevis and *Paenibacillus polymixa* were tested for antagonistic activity against five *Phytophthora* species, including *P. ramorum.* Both antagonists significantly inhibited *P.*

ramorum in vitro, but were ineffective in inoculation assays of leaves dipped in a cell suspension 24 hours to inculation with a *Phytophthora* sp. (Linderman and Davis, 2005).

Cultural Control (Sanitation)

Sanitation during and after propagation is necessary to maintain and monitor pathogen-free material (Pegg, 1978 and Hansen, 1970 in Erwin and Ribeiro, 1996). For control of a polycyclic foliar pathogen, such as *P. ramorum*, in the field, sanitation needs to be 99.9% effective (Vanderplank, 1963 in Erwin and Ribeiro, 1996). Sanitation practices should include removing and testing of symptomatic stock, sterilization of potting media, and disinfection of tools, benches, workers' shoes, gloves and equipment (Erwin and Ribeiro, 1996). All symptomatic material or diseased plants should be disposed in a sanitary landfill or otherwise treated to prevent the spread of *P. ramorum*.

Irrigation water can be a pathway for dissemination of *Phytophthora* species (Erwin and Ribeiro, 1996), especially in water that is re-circulated. A source of pathogen-free water is necessary to prevent infection. A variety of methods to disinfest water exists, including ozonation, chlorination, filtration and UV irradiation (Jarvis, 1992; von Broembsen, 2005). Kaminski *et al.* (2005) built and tested three different filtration systems for the non-chemical elimination of *P. ramorum*.

Physical Control

The use of heat and vacuum in combination prevented recovery of *P. ramorum* from leaves of *U. californica*, while maintaining the volatiles needed in the leaves for cooking. However, the lack of recovery of the pathogen does not necessarily mean the pathogen has been devitalized (Harnik *et al.*, 2004). Linderman and Davis (2005) demonstrated that *P. ramorum* can readily survive in potting media or soil after deliberate contamination with culture-produced sporangia or chlamdydospores. They detected the pathogen for six months by baiting or direct plating from all contaminated substrates. *P. ramorum* sporangia survived best in peat moss, potting mix, coir, and Douglas Fir bark, and poorest in sand or soil. They also found that the use of heat via aerated steam mixtures, at temperatures of 60º C or higher, was an effective means of eradicating *P. ramorum* from infested media and contaminated containers without destroying the containers.

Best Management Practices

The Nursery Committee of the California Oak Mortality Task Force has formulated best management practices to control or eliminate diseases caused by *P. ramorum* (Suslow *et al.*, 2004). They divided the practices into three categories: exclusion, prevention and monitoring.

C. WOOD AND WOOD PRODUCTS

The unique situation with woody canker hosts is that sporulation is not observed on the surface of cankers; however, the pathogen can be isolated from bark and wood chips (Davidson *et al.*, 2003). The pathogen was also recovered from firewood stored for 6 months (Shelly *et al.*, 2005a). Sporulation in baiting trials was stimulated when inoculated "logs" were kept at 12°C prior to baiting (Matteo Garbelotto, per. comm.). Studies are needed to determine if chlamydospores are produced in bark (phloem) and wood (xylem), and if so, whether these spores are destroyed by drying. Techniques should be developed to assess dormancy (viability) versus death of chlamydospores.

Physical treatments

Cut wood of *Quercus* is allowed entry from North America into the United Kingdom if appropriately prepared to address the risk of moving oak wilt disease. These preparations, or conditions of entry include that the wood be stripped of bark and squared to remove entirely the rounded surface or the wood contains less than 20% water as a percentage of dry matter or, for sawn wood only, whether debarked or not, kiln dried to below 20% moisture content. (Annex IV, Part A, Section 1, 3) (Anon., 2000). Exceptionally, and for some EU Member States only, oak logs intended for veneer production are allowed entry by derogation subject to fumigation only (Commission Decision 93/467/EEC [OJ No. L 217, 27.8.1993, p.49] as last amended by Commission Decision 2000/780/EC [OJ No. L 309, 9.12.2000, p.35]).

Prescribed periods and conditions for air-drying or heat treatment are possible mitigation procedures for wood products. *P. ramorum* was not recovered from infected wood chips after two weeks of air-drying (Swain *et al.*, 2002). This is inconclusive, however, until research is conducted that will elucidate dormancy of the pathogen. The chlamydospores of several *Phytophthora* species are able to withstand adverse conditions, an ability usually attributed to oospores (Erwin and Ribeiro, 1996). Evidence of the stage(s) of the pathogen occurring in the bark, cambium and xylem is needed, as are the effects of different drying/heating mechanisms on the pathogen.

Debarking is a currently required by Canada as a mitigation measure. No products containing bark originating in the quarantined zones in the United States are allowed entry by Canada. There is evidence that the pathogen can infect up to 18 cm (Hansen, 2002). Debarking would not remove infected material this deep in the log.

Swain *et al.* (2003) found that colony growth of *P. ramorum* was completely arrested after exposure to 55°C for one hour or longer, whereas a two-hour exposure was required at 45°C. The maximum temperature allowed in compost, 140°F (60°C) is compatible with IPPC requirements for heat treatment of solid wood packing materials, but the materials in compost remain near the maximum temperature for more than the 30 minutes at the core required by IPPC. Heat may not be the only factor detrimental to this pathogen in the composting process. Microbial competition or other biological activity or products resulting from digested plant material may play a role in reducing inoculum.

Bark used for mulch is often placed in huge compost piles and the temperature within those piles is allowed to exceed the 140°F (60°C) requirement for compost. Research is needed to determine procedures for handling bark, including a monitoring system and provisions to prevent contamination.

Magnusson *et al.* (2001) listed methods to mitigate the risk for other pathogens and pests in wood chips: heat treatment, pressure impregnation at temperature and pressures to kill fungi, insects and nematodes, and in-transit shipboard fumigation. They also noted that economically feasible treatments for wood chips are currently lacking leaving regulation of trade the sole strategy.

Chemical Control

P. ramorum is susceptible to label-dosages of copper sulfates and copper hydroxides. In different formulations, it is moderately susceptible to mancozeb. The pathogen is sensitive to phosphites or phosphonates. On *Quercus* spp. and *L. densiflorus* phosphite injections are effective while phosphite foliar sprays are not (Garbelotto *et al.*, 2002c; Kanaskie *et al.,* 2005). The pathogen is extremely sensitive to metalaxyl, but drenches and foliar sprays are ineffective in *Quercus* spp. (Garbelotto *et al.*, 2002b; Harnik and Garbelotto, 2005).

A combination of injection and topical applications of phosphonate on *Q. parvifolia* var. *schrevei* was more effective than either treatment alone. All three treatments were more effective than the control for *L. densiflorus* and dosage may be as important as the application method (Schmidt *et al*., 2005). Range in susceptibility of the hosts to the pathogen may affect the outcome of the treatment.

Methyl bromide has been used as a fumigant for wood products, but the data on control of fungi and related organisms in wood are limited. However, methyl bromide has a long history for soil fumigation in the field and greenhouse (Erwin and Ribeiro, 1996). It has commonly been used in combination with chloropicrin for control of *Phytophthora* species and other pests in strawberry beds (Wilhelm and Paulus, 1980), and has been used for soil treatment for the mitigation of *P. cinnamomi* in citrus groves (Menge and Nemec, 1997).

Cultural and Biological Control

Recommendations to reduce the likelihood of infection of *Quercus* and *L. densiflorus* by *P. ramorum* are to prevent over-watering and excess nitrogen applications (Garbelotto, COMTF Spring Meeting, May 28, 2003). Trees with higher water potentials are at a higher risk for infection than trees with less than optimal water potentials (Swiecki and Bernhardt, 2002a,b). Factors that encourage rapid growth of trees cause natural openings and thinner cells in the outer bark, and may increase the efficiency of infection by *P. ramorum*.

A number of cultural methods are used to mitigate root rot and canker diseases of citrus caused by *P. cinnamoni* and *P. citrophthora* including management of source and amount of nitrogen and water (Menge and Nemec, 1997). Elevated levels of calcium, phosphorus, iron and copper are inhibitory to zoospores of these two species. Most of the measures, however, are to control

the root rot phase, but the nitrogen and water levels also affect the amount of succulent growth. Menge and Nemec (1997) recommended cultural measures, such as pruning low hanging branches and removal of mulch from trunk, to eliminate moisture on the trunk to prevent canker formation.

In vitro laboratory research with biological antagonists indicated that control was possible, but field tests did not indicate control (Matteo Garbelotto, pers. comm.).

Breeding for Resistance

Through no breeding work has been initiated, levels of resistance are being detected both in and between populations of *U. californica* and *Quercus* (Hüberli *et al*, 2002b; Garbelotto, 2003). Work with a variety of hosts and a variety of *Phytophthora* species indicates strategies to use natural resistance. Menge and Nemec (1997) found that it was important to consider time of year, cultural factors and tissue that is susceptible when screening for resistance.

D. GREENWASTE/COMPOST

Evidence exists that composting, as specified by the California Waste Management Board, may be an effective cultural control of *P. ramorum* in yard waste (Swain *et al.*, 2003; Swain *et al.*, 2005). The maximum temperature allowed in compost is 140°F (60°C). Swain *et al.* (2003) found that colony growth of *P. ramorum* was completely arrested after exposure to 55°C for one hour or longer; a two-hour exposure was required at 45°C. Tests indicate that *P. ramorum* in greenwaste mulch is killed in compost after being held at 55° C for 2 weeks (Garbelotto, 2003). *P. ramorum* could not be recovered by baiting from leaf and twig samples after tunnel composting at a minimum of 60° for 10 hours (Aveskamp and Wingelaar, 2005). Efforts to break dormancy of chlamydospores were not reported. Similar temperatures can be reached in mulch piles and therefore a composting system may be developed (Steve Titko, pers. comm). Additonal information on chlamydospore biology, such as factors inducing and breaking dormancy, is needed before composting methods can be proven as effective control measures. Heat may not be the only factor detrimental to *P. ramorum* in the composting process. Microbial competition or other biological activity or products resulting from digested plant material may play a role in reducing inoculum (Hoitink and Fahy, 1986). Compositing also requires a monitoring program to ensure contamination does not occur (Garbelotto, 2003). Recent research indicates that the source of the material may affect the ability of the composting process to devitalize *P. ramorum* (Swain and Garbelotto, 2005).

E. POTTING MEDIA AND SOIL

Asymptomatic roots and infested potting medium can harbor *P. ramorum* (Parke *et al.*, 2005). Aerated steam mixtures were tested for mitigation potential for *P. ramorum* and other pathogens in potting media in containers. *P. ramorum* could not be recovered from medium subjected to aerated steam mixtures of 60°, 65° or 75°C for 30 minutes (Linderman and Davis, 2005).

Sanitation by removal of plant debris and humus reduced the level of *P. ramorum* recovered by baiting at the soil surface but did not affect recovery at 20 cm (Aveskamp *et al.,* 2005).
P. ramorum survived in sandy soil for at least one year (Aveskamp *et al.,* 2005).

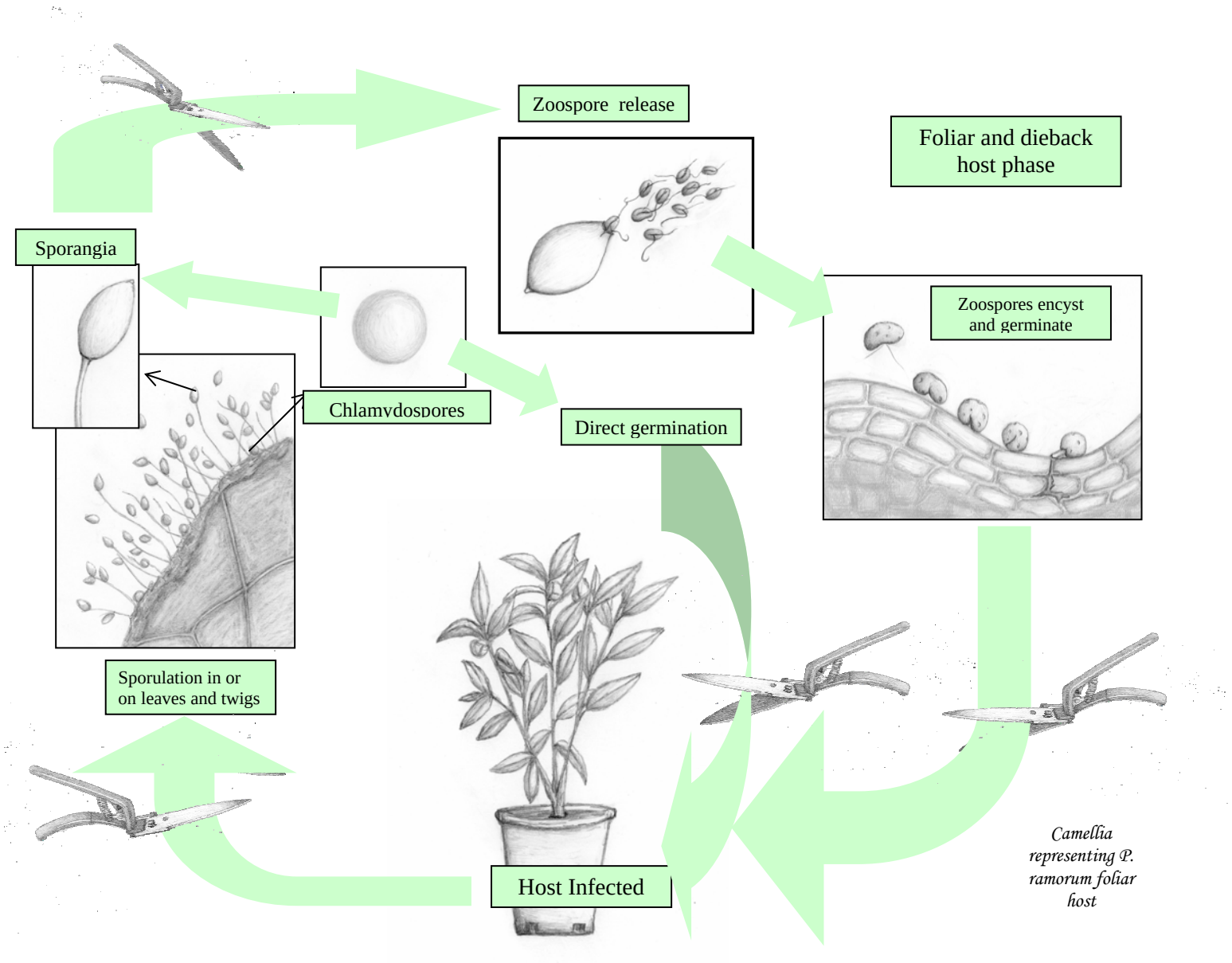

Fig. 4. Potential points for the application of mitigation measures for the foliar host phase are indicated with pruning shears

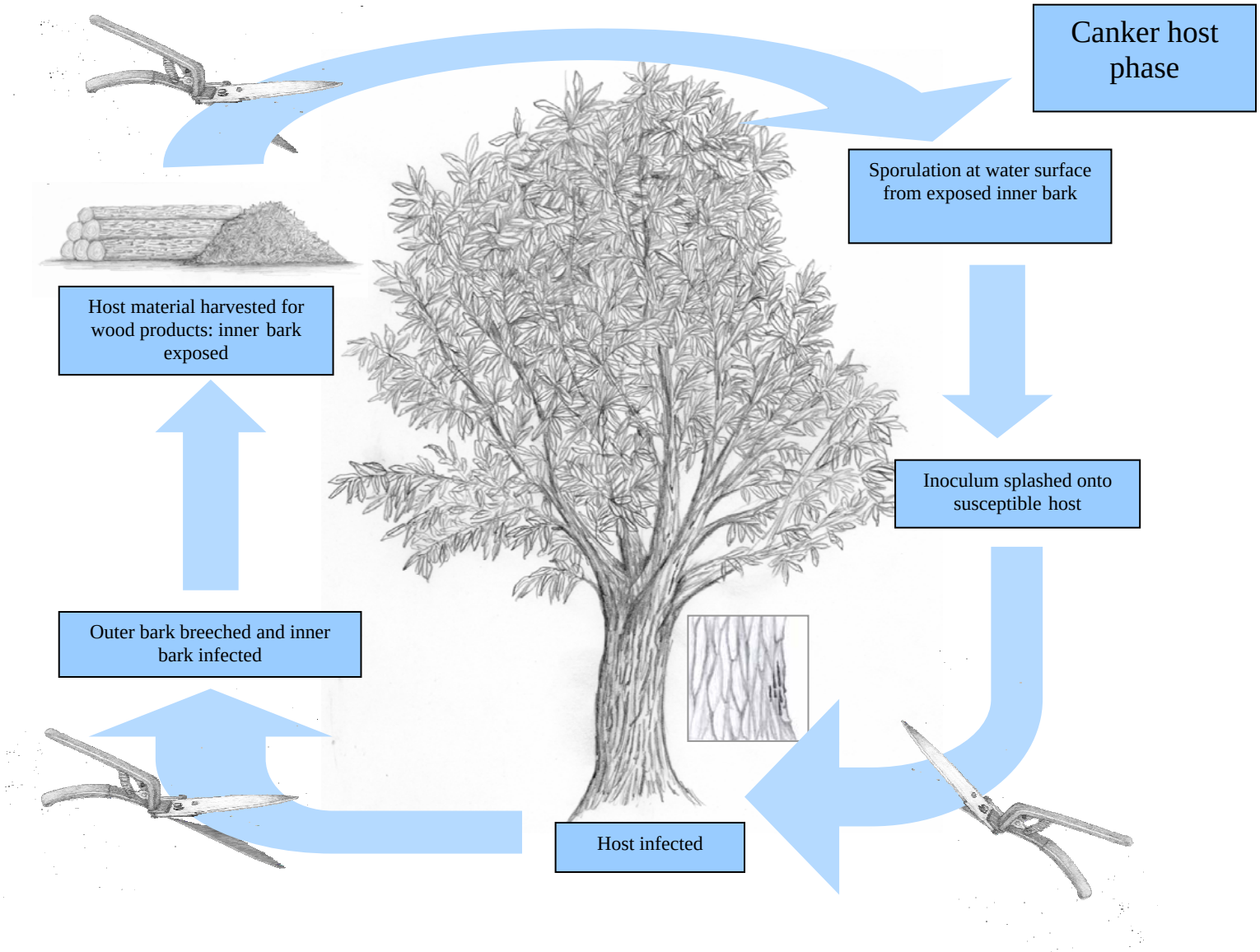

Fig. 5. Potential points for the application of mitigation measures for the canker host phase are indicated with pruning shears.

Table 6. Fungicides labeled for control of *Phytophthora* diseases[1].

ACTIVE INGREDIENT	PRODUCT	COMPANY	REGISTERED
Azoxystrobin	Amistar	Syngenta	Vegetable crops
Chlorothalonil	Daconil Ultrex	Syngenta	Ornamentals
Chlorothalonil	Echo 720 T&O	SipCam Agro	Turf, ornamentals
Copper hydroxide	Champ Formula 2 flowable, wp	Nufarm	Ornamentals
Copper hydroxide	Champion WP	Nufarm	Ornamentals
Copper hydroxide	Kocide 2000 T/N/O	Griffin	Turf, ornamentals
Dimethomorph	Acrobat 50WP, MZ	BASF	Potatoes
Etridiazole	Banrot 40WP, 8G	Scotts	Ornamentals
Etridiazole	Terrazole 35WP	Crompton-Uniroyal	Ornamentals
Etridiazole	Truban 25EC, 30WP, 5G	Scotts	Turf, ornamentals
Fluaxinam	Omega 500F	Syngenta	Peanuts and potatoes
Mancozeb	Dithane 75 DF	Dow	Ornamentals
Mancozeb	Fore	Dow	Turf, ornamentals
Mancozeb	Gavel 75 DF	Dow	Vegetable crops
Mancozeb+Cu(OH)2	Mankocide	Griffin	Fruits and vegetables
Mefanoxam	Apron XL LS	Syngenta	Vegetable crops
Mefanoxam	Mefanoxam 2	SipCam Agro	Ornamentals
Mefanoxam	Ridomil Gold	Syngenta	Fruits and vegetable
Phosphonate	Aliette WDG Chipco	Bayer	Turf, ornamentals
Phosphonate	Phostrol	Nufarm	Fruits and vegetables
Phosphonate	Vital	Griffin	Ornamentals
Propamocarb	Banol	Bayer	Turf, ornamentals
Pyraclostrobin	Cabrio EG	BASF	Fruits and vegetables
Pyraclostrobin	Headline	BASF	Vegetable crops
Trifloxystrobin	Flint	Bayer	Fruits and vegetables

[1]This list is not comprehensive, and does not constitute an endorsement, by USDA, of any products listed here.

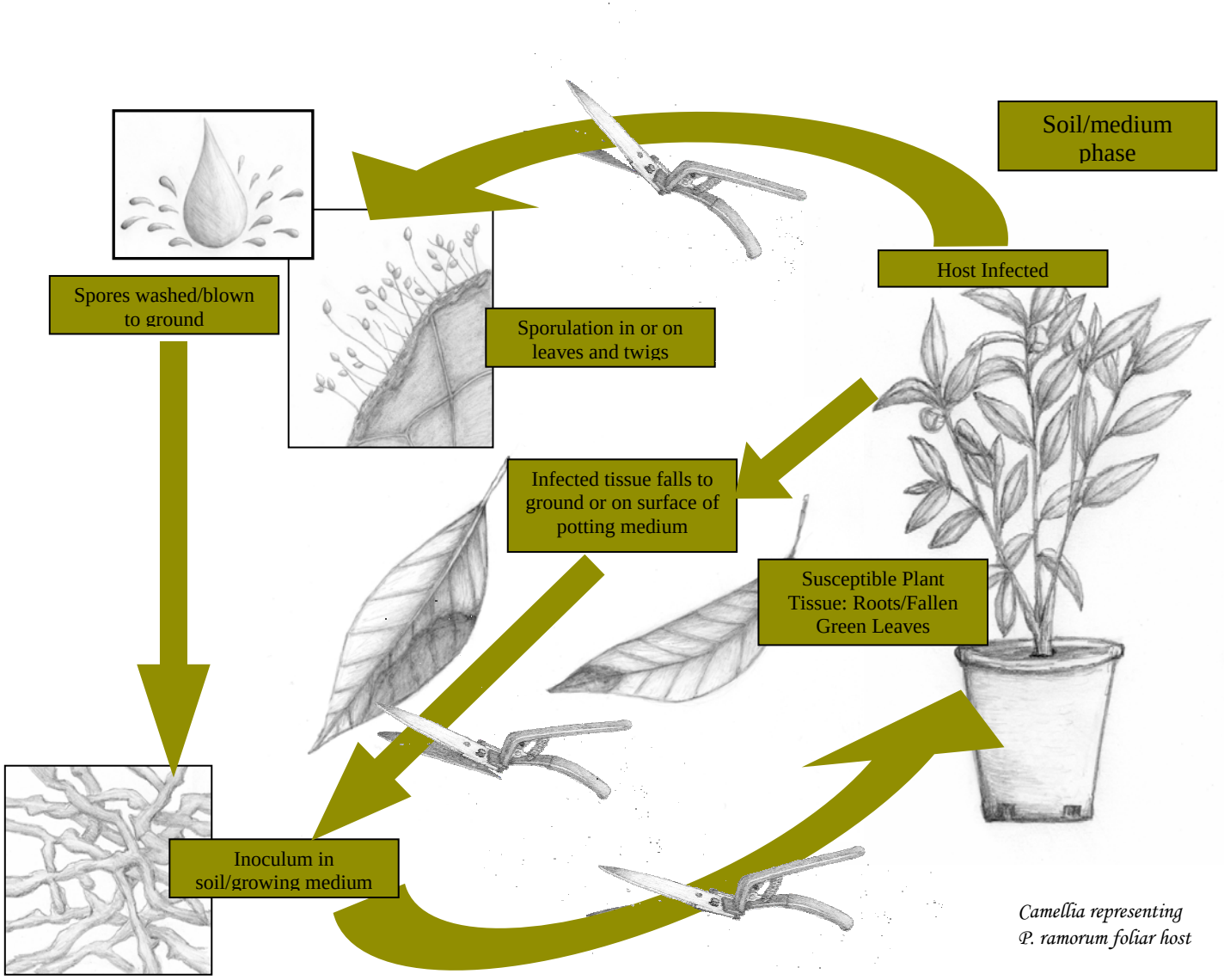

Fig. 6. Potential points for the application of mitigation measures for the soil phase are indicated with pruning shears.

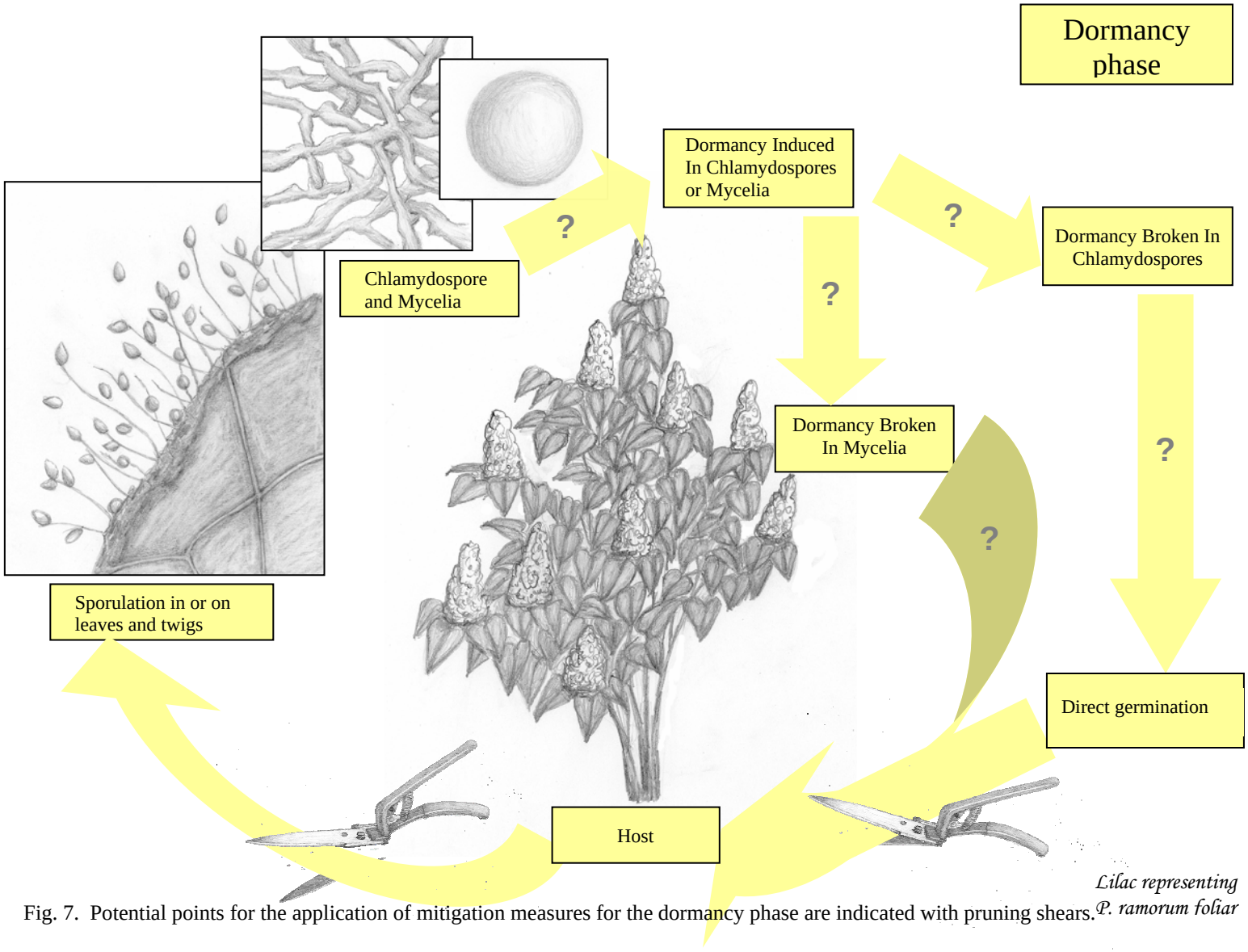

Fig. 7. Potential points for the application of mitigation measures for the dormancy phase are indicated with pruning shears.

VII. ACKNOWLEDGEMENTS

Contributors
Lynn Garrett, Economist, USDA-APHIS-PPQ-CPHST, Raleigh, NC
Russell Bulluck, National Program Staff Scientist, USDA-APHIS-PPQ-CPHST, Raleigh, NC
Heather Hartzog, Plant Pathologist, USDA-APHIS-PPQ-CPHST-PERAL, Raleigh, NC

Reviewers

Staff of APHIS Pest Detection and Management Programs and Staff of Center for Plant Health Science and Technology, Plant Epidemiology and Risk Analysis Laboratory.

VIII. LITERATURE CITED

Agrios, G. N. 1997. Plant Pathology. 5th Edition. San Diego, CA: Academic Press. 635 pp.

APHIS. 2002. Guidelines for Pathway-Initiated Pest Risk Assessment. United States Department of Agriculture Animal and Plant Health Inspection Service (APHIS). Version 5.02. http://www.aphis.usda.gov/ppq/pra/commodity/cpraguide.pdf

APHIS. 2004. Soil and Potting Medium Sampling and Baiting for *Phytophthora ramorum* in Infested or Potentially Infested Nurseries. United States Department of Agriculture Animal and Plant Health Inspection Service (APHIS)Version 1.3, 7 May 2004. Retrieved February 24. 2005 from http://www.aphis.usda.gov/ppq/ispm/pramorum/soilsamplingprotocol.html

APHIS. 2005a. Program Update for *Phytophthora ramorum.* United States Department of Agriculture Animal and Plant Health Inspection Service (APHIS) Pest Detection and Management Programs. January 10, 2005. Retrieved March 23, 2005 from http://www.aphis.usda.gov/ppq/ispm/pramorum/

APHIS. 2005b. APHIS List of Plants Regulated and Associated with *Phytophthora ramorum.* United States Department of Agriculture Animal and Plant Health Inspection Service (APHIS). Revised January 10, 2005. Retrieved February 11, 2005 from http://www.aphis.usda.gov/ppq/ispm/pramorum/pdf_files/usdasodlist.pdf

APHIS. 2005c. Program Update for *Phytophthora ramorum.* United States Department of Agriculture Animal and Plant Health Inspection Service (APHIS) Pest Detection and Management Programs. March 7, 2005. Retrieved March 23, 2005 from http://www.aphis.usda.gov/ppq/ispm/pramorum/

APHIS. 2005d. *Phytophthora ramorum* (Pr) also known as Sudden Oak Death, ramorum leaf blight and ramorum dieback. United States Department of Agriculture Animal and Plant Health Inspection Service (APHIS) Pest Detection and Management Programs. Retrieved March 23, 2005 from http://www.aphis.usda.gov/ppq/ispm/pramorum/

APHIS. 2005e. Official Regulatory Protocol for Nurseries Containing Plants Infected with *Phytophthora ramorum* (Sudden Oak Death). Revised 15 October 2004 (Minor Updates on 17 March 05). Retrieved April 1, 2005 from http://www.aphis.usda.gov/ppq/ispm/pramorum/pdf_files/cnpv031705.pdf

Aveskamp, M. M. and G. J. Wingelaar. 2005. Elimination of *Phytophthora ramorum* in the tunnel-composting process. [abstract], p. 121 *in* Sudden Oak Death Second Science Symposium The State of Our Knowledge. January 18-21, 2005, Monterey, California

Aveskamp, M. M., P. J. M van Baal, and J. de Gruyter. 2005. Effect of sanitary measures on the survival of *P. ramorum* in soil. [abstract], p. 60 *in*: Sudden Oak Death Second Science Symposium The State of Our Knowledge. January 18-21, 2005, Monterey, California

Bachman, J. 2002. Woody ornamentals for cut flower growers. Appropriate Technology Transfer for Rural Areas. National Center for Appropriate Technology. Retrieved May 2, 2005 from http://attra.ncat.org/attra-pub/PDF/woodyornamentals.pdf

Bailey, L. H. and E. Z. Bailey. 1976. Hortus Third. New York: MacMillan Publishing Co., Inc. 1290 pp.

Beales, P. A., T. Brokenshire, A. V. Barnes, V. C. Barton and K. J. D. Hughes. 2004a. First report of ramorum leaf blight and dieback (*Phytophthora ramorum*) on *Camellia* spp. in the UK. Plant Pathology 53: 524.

Beales, P. A., A. Schlenzig and A. J. Inman. 2004b. First report of ramorum bud and leaf blight (*Phytophthora ramorum*) on *Syringa vulgaris* in the UK. Plant Pathology 53: 525.

Brasier, C. M., J. Roase, S. A. Kirk, and J. F. Webber. 2002. Pathogenicity of *Phytophthora ramorum* isolates from North America and Europe to bark of European Fagaceae, American *Quercus rubra,* and other forest trees [abstract], pp. 30-31 *in*: Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley. http://danr.ucop.edu/ihrmp/sodsymposium.html

Brasier, C. 2003. Sudden Oak Death: *Phytophthora ramorum* exhibits transatlantic differences. Mycological Research 107: 258-259.

Brasier, C., J. Rose, S. Kirk, and J. Webber. 2003. Pathogenicity of *Phytophthora ramorum* isolates from USA and Europe to bark of European forest trees (abstract). 8th International Congress of Plant Pathology, Christchurch, New Zealand (2003-02-02/07).

Brasier, C., P. Beales, S. Kirk, V. Barton, P. Giltrap, R. Griffin, K. Hughes, C. Lane, J. Rose, S. Denham and J. Webber. 2004a. A new *Phytophthora* species affecting European Beech (*Fagus sylvatica*) and *Rhododendron* in the UK (poster). *Phytophthora ramorum*: A review of North American and European Activity: California Oak Mortality Task Force Annual Meeting, March 10, 2004.

Brasier, C.M., S. Denman, A. Brown and J.A. Webber. 2004b. Sudden oak death (*Phytophthora ramorum*) discovered on trees in Europe. Mycol. Res. 108(10): 1107-1110.

Brasier, C. M., S. Denman, J. Rose, S. A. Kirk, K. J. D. Hughes, R. L. Griffin, C. R. Lane, A. J. Inman and J. F. Webber. 2004c. First report of ramorum bleeding canker on *Quercus falcata* caused by *Phytophthora ramorum*. Plant Pathology 53: 804.

Browning, M., L. Englander and P. W. Tooley. 2003. Factors influencing growth and sporulation of *Phytophthora ramorum,* causal agent of sudden oak death. Phytopathology 93: S12.

CFIA. 2001. Quarantine regulation. Canadian Food Inspection Agency (CFIA).

CFIA. 2003a. Canadian Food Inspection Agency, News Release, June 13, 2003 from http://www.inspection.gc.ca/english/corpaffr/newcom/2003/20030613e.shtml

Chastagner, G. A., E. M Hansen, K. L. Riley and W. Sutton. 2004. Susceptibility of conifer shoots to infection by *Phytophthora ramorum*. Phytopathology 94: S16.

Chastagner, G. A., E. M Hansen, K. L. Riley and W. Sutton. 2005a. Effectiveness of fungicides in protecting Douglas-fir shoots from infection by *Phytophthora ramorum.* [abstract], p. 45 *in* Sudden Oak Death Second Science Symposium The State of Our Knowledge. January 18-21, 2005, Monterey, California.

Chastagner, G. A., E. M Hansen, K. L. Riley and W. Sutton. 2005b. Susceptibility of conifer shoots to infection by *Phytophthora ramorum*. [abstract], p. 25 *in* Sudden Oak Death Second Science Symposium The State of Our Knowledge. January 18-21, 2005, Monterey, California.

COMTF. 2003a. January Monthly Report, California Oak Mortality Task Force. Retrieved February 20, 2004 from http://www.cnr.berkeley.edu/comtf/

COMTF. 2003b. June Monthly Report, California Oak Mortality Task Force. Retrieved February 20, 2004. http://www.cnr.berkeley.edu/comtf/

COMTF. 2004a. A guide for recreational users: Simple precautions to prevent the spread of Sudden Oak Death. California Oak Mortality Task Force, September, 2004. Retrieved March 1, 2005 from http://www.suddenoakdeath.org/

COMTF. 2004b. December Monthly Report, California Oak Mortality Task Force. Retrieved March 16, 2004 from http://www.cnr.berkeley.edu/comtf/

COMTF. 2004c. March Monthly Report, California Oak Mortality Task Force. Retrieved March 16, 2004 from http://www.cnr.berkeley.edu/comtf/

COMTF. 2005. Nursery Chronology. California Oak Mortality Task Force. Retrieved May 4, 2005 from http://nature.berkeley.edu/comtf/html/chronology.htm

Cree, L., E. Allen and D. McKenney. 2001. Sudden Oak Death *Phytophthora ramorum*: Plant Health Risk Assessment PRA # 00-39 Draft. October 2001. Canadian Food Inspection Agency.

Cree, L. 2002. *Phytophthora ramorum*, Sudden Oak Death. Pest Fact Sheet. February, 2002. Canadian Food Inspection Agency.

Cushman, J. H. and R. K. Meentemeyer. 2005. The role of humans in the dispersal and spread of Phytophthora ramorum. [abstract], p. 43 *in*: Sudden Oak Death Second Science Symposium The State of Our Knowledge. January 18-21, 2005, Monterey, California.

Daily, G. (ed.). 1997. Nature's Services: Societal Dependence on Natural Systems, Washington, DC: Island Press.

Davidson, J. M., and M. Garbelotto. 2001. Transmission of *Phytophthora* associated with Sudden Oak Death in California. Phytopathology 91: S108.

Davidson, J. M., M. Garbelotto, S. T. Koike, and D. M. Rizzo. 2002a. First Report of *Phytophthora ramorum* on Douglas-Fir in California. Plant Dis. 86: 1274.

Davidson, J. M., P. E. Maloney, A. C. Wickland, A. C. Morse, C. E. Jensen, and D. M. Rizzo. 2002b. Transmission of *Phytophthora ramorum* via *Umbellularia californica* (California bay) leaves in California oak woodlands [abstract], p. 9 *in*: Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley. http://danr.ucop.edu/ihrmp/sodsymposium.html

Davidson, J. M., D. M. Rizzo, M. Garbelotto, S. A. Tjosvold, and G. W. Slaughter. 2002c. *Phytophthora ramorum* and sudden oak death in California: II. Transmission and survival. Pages 741-749 *in* R. Standiford and D. McCreary (eds.) 5th Symposium on California Oak Woodlands. U. S. Dep't. Agric. For. Serv. Gen. Tech. Rep. PSW-GTR-184.

Davidson, J. M., A. C. Wickland, A. C. Morse, C. E. Jensen, R. G. Albright, S. C. Lynch, J. Tse, G. Slaughter, M. Garbelotto, and D. M. Rizzo. 2002d. Spatial Distribution of Disease Caused by *Phytophthora ramorum* in Coast Live Oak Woodlands [abstract], p. 48-49 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley. http://danr.ucop.edu/ihrmp/sodsymposium.html

Davidson, J. M, A. C. Wickland, A. C. Morse, S. A. Tjosvold, D. L. Chambers, C. E. Jensen, G. Slaughter, M Garbelotto, and D. M. Rizzo. 2002e. Transmission of *Phytophthora ramorum* in Coast Live Oak Woodlands [abstract], p. 8 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley. http://danr.ucop.edu/ihrmp/sodsymposium.html

Davidson, J. M., Rizzo, D. M., Garbelotto, M., Tjosvold, S., Slaughter, G. W. & C.Wickland. 2003a. Evidence for aerial transmission of *Phytophthora ramorum* among *Quercus* and *Lithocarpus* in California woodlands, pp. 108-114 *in* J. A. McComb, G. E. St. J. Hardy and I. C. Tommerup (eds.) '*Phytophthora* in Forests and Natural Ecosystems'. 2nd International IUFRO Meeting on Phytophthora in Forests and Natural Ecosystems, Albany, Western Australia. Perth, Australia: Murdoch University Print.

Davidson, J. M., and C. G. Shaw. 2003b. Pathways of movement for *Phytophthora ramorum*, the causal agent of Sudden Oak Death. Sudden Oak Death Online Symposium. The American Phytopathological Society. Retrieved March 15, 2005, from http://www.apsnet.org/online/SOD/Papers/Shaw_Davidson/default.htm

Davidson, J. M., S. Werres, M. Garbelotto, E. M. Hansen, and D. M. Rizzo. 2003c. Sudden Oak Death and Associated Diseases Caused by *Phytophthora ramorum*. Plant Health Progress 2003-0707-01-DG. Retrieved May 3, 2005 from http://www.plantmanagementnetwork.org/pub/php/diagnosticguide/2003/sod/

Davidson, J. M., A. C. Wickland, H. A.Patterson, K. R. Falk, and D. M. Rizzo. 2005. Transmission of *Phytophthora ramorum* in mixed-evergreen forest in California. Phytopathology 95:587-596.

DEFRA. 2004a. Background – *Phytophthora ramorum*. Department for Environment, Food and Rural Affairs, United Kingdom. Retrieved February 20, 2004 from http://www.defra.gov.uk/planth/oak.htm

DEFRA. 2004b. *Phytophthora ramorum*: a threat to our trees, woodland and healthland. Department for Environment, Food and Rural Affairs, United Kingdom. Retrieved February 20, 2004 from http://www.defra.gov.uk/planth/oak.htm

DEFRA. 2004c. *Phytophthora ramorum* epidemiology: sporulation potential, dispersal, infection, latency and survival. Final Project Report PH0194, Department for Environment, Food and Rural Affairs (DEFRA), United Kingdom. Retrieved December 15, 2004 from http://www.defra.gov.uk/science/project_data/DocumentLibrary/PH0194/PH0194_2004_FRP.pdf

DEFRA. 2004d. Eradication and containment action required against findings of *Phytophthora ramorum* and *Phytophthora kernoviae*. Department for Environment, Food and Rural Affairs, United Kingdom. Page last modified: 14 Oct 2004. Retrieved March 15, 2005 from http://www.defra.gov.uk/planth/newsitems/eradcon.htm

DEFRA. 2005a. *Phytophthora kernoviae* – Frequently Asked Questions. The Forestry Commission, Department of the Environment, Forest and Rural Affairs (DEFRA), United Kingdom. Retrieved February 25, 2005 from http://www.forestry.gov.uk/forestry/infd-5vtlel

DEFRA. 2005b. *Phytophthora ramorum* Industry Liaison Group, Fourth Meeting 22 February 2005. Department of the Environment, Forest and Rural Affairs (DEFRA), United Kingdom. Retrieved March 22, 2005 from http://www.defra.gov.uk/planth/newsitems/industry.htm

de Gruyter, H., A. de Haas, and B. de Hoop. 2002b. Report of a PRA. *Phytophthora ramorum.* Netherlands Plant Protection Service. Draft version, July 18, 2002.

Dodd, R. S., D. Huberli, V. Douhovnikoff, R. Harnik, Z. Afzal-Rafii, and M. Garbelotto. 2002b. Towards a Model of the Genetic Architecture of *Phytophthora ramorum* Susceptibility in Coast Live Oak [abstract], p. 35 *in*: Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley. http://danr.ucop.edu/ihrmp/sodsymposium.html.

EPPO. 2004. *Phytophthora ramorum* Sudden Oak Death. European Plant Protection Organization Panel Review: 2004-03. Retrieved January, 2004 from http://www.eppo.org/QUARANTINE/Alert_List/fungi/oak_death.htm

Erwin, D. C., and O. K. Ribeiro. 1996. *Phytophthora* diseases worldwide. St Paul, Minnesota: APS Press. 562 pp.

FAO. 1996. ISPM # 02: Guidelines for pest risk analysis (Standards). International Standards for Phytosanitary Measures. International Plant Protection Convention Secretariat, FAO, United Nations, Rome, Italy.

FAO. 2002. ISPM # 5: Glossary of Phytosanitary Terms 2002. International Standards for Phytosanitary Measures. International Plant Protection Convention Secretariat, FAO United Nations, Rome, Italy.

Fichtner, E. J., S. C. Lunch, and D. M. Rizzo. 2004. Survival of *Phytophthora ramorum* in infected leaf tissue at the soil surface in a tanoak-redwood forest [abstract]. Conference of *Phytophthoras in* Forest and Natural Ecosystems. International Union of Forest Research Organizations. Retrieved January 13, 2005 from http://www.lwf.uni-muenchen.de/iufro-online/index.html

Fichtner, E. J., S. C. Lunch, and D. M. Rizzo. 2005a. Detection and distribution of *Phytophthora ramorum* in redwood-tanoak forest community soils [abstract], p. 97 *in* Sudden Oak Death Second Science Symposium The State of Our Knowledge. January 18-21, 2005, Monterey, California.

Fichtner, E. J., S. C. Lunch, and D. M. Rizzo. 2005b. Summer survival in *Phytophthora ramorum* in forest soils [abstract], p. 45 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Garbelotto, M., and D. M. Rizzo. 2001. Preliminary studies on chemical and cultural control of *Phytophthora* associated with sudden oak death. Phytopathology 91: S30.

Garbelotto, M., D. M. Rizzo, and J. M. Davidson. 2001. Studies in the genetics of a new *Phytophthora* species associated with Sudden Oak Death in California. Phytopathology 91:S110.

Garbelotto, M., Rizzo, D. M., Davidson, J. M. and S. J. Frankel. 2002a. How to recognize the symptoms of the diseases caused by *Phytophthora ramorum*, causal agent of Sudden Oak Death. USDA Forest Service, Pacific Southwest Region publication, pp. 1-15.

Garbelotto, M., D. M. Rizzo, K. Hayden, M. Meija-Chang, J. M. Davidson and S. Tjosvold. 2002b. Phytophthora ramorum and sudden oak death in California. III. Pathogen genetics *in* R. Standiford and D. McCreary (eds.) 5th symposium on California Oak Woodlands. USDA Forest Service, Gen Tech PSW-GTR-184. pp. 765-774.

Garbelotto, M., D. M. Rizzo, and L. Marais. 2002c. *Phytophthora ramorum* and Sudden Oak Death in California: IV. Chemical control, *in* 5th Symposium on California Oak Woodlands, R. Standiford and D. McCreary, (eds.), USDA Forest Service, General Technical Report, PSW-GTR-184: 811-818.

Garbelotto, M. 2003. Providing a solution composting as a control for sudden oak death disease. Biocycle 44: 53-56.

Garbelotto, M, J. M. Davidson, K. Ivors, P. E. Maloney, D. Huberli, S. T. Koike and D. M. Rizzo. 2003. Non-oak native plants are main hosts for sudden oak death pathogen in California. California Agriculture 57(1): 18-23.

Garbelotto, M., K. Ivors, and P. Bonants. 2004. Microsatellite analysis reveals genetic variation in *Phytophthora ramorum*, mitotic recombination, and sexual recombination between A1 And A2 [abstract]. Conference of *Phytophthoras* in Forest and Natural Ecosystems, September 11-17, 2004.. International Union of Forest Research Organizations. Retrieved January 13, 2005 from http://www.lwf.uni-muenchen.de/iufro-online/index.html

Giltrap, P. M., A. J. Inmana, V. C. Bartona, A. V. Barnesa, C. R. Lanea, K. J. D. Hughesa, J. Tomlinsona, M. L. Deanb and K. Izzardc. 2004. First report of ramorum dieback (*Phytophthora ramorum*) on *Hamamelis virginiana* in the UK. Plant Pathology 53: 526.

Goheen, E.M., E. M. Hansen, A. Kanaskie, M. G. McWilliams, N. Osterbauer, and W. Sutton. 2002a. Sudden oak death caused by *Phytophthora ramorum* in Oregon. Plant Disease 86:441.

Goheen, E.M., E. M. Hansen, A. Kanaskie, M. G. McWilliams, N. Osterbauer, and W. Sutton. 2002b. Eradication of sudden oak death in Oregon. Phytopathology 92: S30. Publication number P-2002-0213-AMA.

Goheen, E., E. Hansen, A. Kanaskie, M. McWilliams, N. Osterbauer, and W. Sutton. 2002c. Plant species naturally infected by *Phytophthora ramorum* in Oregon forests [abstract], p. 76-77. *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley.. http://danr.ucop.edu/ihrmp/sodsymposium.html.

Goheen, E., E. Hansen, W. Sutton, A. Kanaskie, M. McWilliams, and N. Ostebauer. 2002d. Epidemiology of *Phytophthora ramorum* in Oregon forests [abstract], p.10 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California – Berkeley. http://danr.ucop.edu/ihrmp/sodsymposium.html.

Goheen, E., M. McWilliams, A. Kanaskie, N. Osterbauer, E. Hansen, and W. Sutton. 2002e. Sudden oak death surveys in Oregon—2001 and 2002 [abstract], p. 23 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley. http://danr.ucop.edu/ihrmp/sodsymposium.html

Goheen, E. M., A. Kanaskie, J. Parke, M. Roth, N. Osterbauer, and A. Trippe. 2005. Applications of fungicides to protect four hosts from foliar infection by *Phytophthora ramorum* in Curry County, Oregon. [abstract], p. 100 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Hall, J. P. and B. Moody. 1994. Forest Depletions Caused by Insects and Diseases in Canada 1982-1987. Forest Insect and Disease Survey Information Report ST-X-8, Ottawa, Canada: Forest Insect and Disease Survey, Canadian Forest Service, Natural Resources Canada.

Hansen, E., W. Sutton, J. Parke, and R. Linderman. 2002. *Phytophthora ramorum* and Oregon forest trees—one pathogen, tree diseases [abstract], pp. 78-79 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley. http://danr.ucop.edu/ihrmp/sodsymposium.html

Hansen, E. M., P. W. Reeser, W. Sutton, and L. M. Winton. 2003a. First report of A1 mating type of *Phytophthora ramorum* in North America. Plant Disease 87: 1267

Hansen, E.M., P. Reeser, J.M. Davidson, M. Garbelotto, K. Iverson, L. Douhan, and D.M. Rizzo. 2003b. *Phytophthora nemorosa*, a new species causing cankers and leaf blight of forest trees in California and Oregon, U.S.A. Mycotaxon 88: 129-138.

Hansen, E.M. and W. Sutton. 2005. Persistence of *Phytophthora ramorum* after eradication efforts in Oregon Tanoak Forests. [abstract], p. 101 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Hansen, E. M., J. L. Parke and W. Sutton. 2005. Susceptibility of Oregon forest trees and shrubs to *Phytophthora ramorum*: A comparison of artificial inoculation and natural infection. Plant Disease 89: 63-70.

Harnik, T. Y., M. Mejia-Chang, J. Lewis and M. Garbelotto. 2004. Efficacy of heat-based treatments in eliminating the recovery of the sudden oak death pathogen (*Phytophthora ramorum*) from infected California bay laurel leaves. HortScience 39(7): 1677-1680.

Harnik, T. Y. and M. Garbelotto. 2005. Effect of chemicals on hyphal growth, sporangia production and zoospore germination of *Phytophthora ramorum*. [abstract], p. 102 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Hartmann, H. T., D. E. Kester, F. T. Davies, Jr., and R. L. Geneve. 2002. Hartmann and Kester's Plant Propagation Principles and Practices, 7th Ed. Upper Saddle River, NJ: Prentice Hall. 880 pp.

Hayden, K., J. Tse, K. Ivors, M. Garbelotto, and C. Bloomquist. 2002. PCR-based detection of *Phytophthora ramorum* in plant tissue [abstract], p. 15 *in*: Proceedings of the Sudden Oak Death, A Science Symposium. USDA Forest Service and University of California, Berkeley, from http://danr.ucop.edu/ihrmp/sodsymposium.html.

Hayden, K. J., D. Rizzo., J. Tse and M. Garbelotto. 2004. Detection and quantification of *Phytophthora ramorum* from California forests using a real-time polymerase chain reaction assay. Phytopathology 94: 1075-1083.

Heungenis, K., I De Dobbelaere, and M Maes. 2005. Fungicide control of *Phytophthora ramorum* on Rhododendron. [abstract], p. 46 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Hoitink, H. A. J. and P. C Fahy. 1986. Basis for the control of soilborne palnt pathogens with compsts. Ann. Rev. Phytopathol. 24: 93-114.

Hüberli, D., E. Simms, C. Carmichael, and M. Garbelotto. 2002a. Worldwide plant hosts of *Phytophthora ramorum* [abstract], p. 79 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley, from http://danr.ucop.edu/ihrmp/sodsymposium.html

Hüberli, D., W. van Sant, S. Swain, J. Davidson, and M. Garbelotto. 2002a. Resistance of *Umbellularia californica* (Bay Laurel) to *Phytophthora ramorum* [abstract], p. 36 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley, from http://danr.ucop.edu/ihrmp/sodsymposium.html.

Hüberli, D., K. L. Ivors, A. Smith, J. G. Tse, and M. Garbelotto. 2005. First report of foliar infection of *Maianthemum racemosum* by *Phytophthora ramorum*. Plant Disease 89: 204.

Inman, A. J., P. A. Beales, C. R. Lane, and C. Brasier. 2002. Comparative Pathogenicity of European and American Isolates of *Phytophthora ramorum* to Leaves of Ornamental Hedgerow and Woodland Understory Plants the UK [abstract], pp. 80-81 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Ivors, K. L., K. J. Hayden, P. J. M. Bonants, D. M. Rizzo and M. Garbelotto. 2004. AFLP and phylogenetic analyses of North American and European populations of *Phytophthora ramorum.* Mycol. Res. 108 (4): 378–392.

Ivors, K. and M. Garbelotto. 2002. TaqMan PCR for detection of *Phytophthora* DNA in environmental plant samples [abstract], p. 56 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Jang, E. B. and H. R. Moffitt. 1994. Systems approaches to achieving quarantine security. In: Quarantine treatments for pests on food plants. Westview Press pp. 225-237.

Jarvis, W. R. 1992. Managing Diseases in Greenhouse Crops. St. Paul, MN: APS Press. 288 pp.

Jerado, A. 2004. Floricultural and Nursery Crop, Situation and Outlook Yearbook. USDA, Economic Research Service. FLO-2004.

Jones, D. R. 2002a. Datasheet for *Phytophthora ramorum*. CSL (Central Science Laboratory), York UK: 11 January 2002: PPP 9602.

Jones, D. R. 2002b. Revised pest risk assessment of the *Phytophthora ramorum*. CSL (Central Science Laboratory), York, UK: 11 January 2002:PPP 9602.

Jones, D. R., S. Sansford, and C. Brasier. 2003. Sudden Oak Death. Summary Pest Risk Analysis. Revision Number: 3. Date: 20 March 2003. Central Science Laboratory, UK Department of Environment, Food and Rural Affairs and Forest Research, UK Forestry Commission. Retrieved May 5, 2004 from http://www.defra.gov.uk/planth/pra/sudd.pdf

Jones, J. 2003. Report to COMTF Nursery Committee, June 17, 2003. California Oak Mortality Task Force.

Jones, R. K. and D. M. Benson (eds.). 2001. Diseases of woody ornamentals and trees in nurseries. St. Paul, MN: APS Press. 482 pp.

Kaminski, K., T. Ufer, H. Beltz, R. Lüttmann, M Posner, H-P. Wessels, and T. Brand. 2005. Introduction of filtration systems in container nurseries for non-chemical elimination of *Phytophthora* spp. from irrigation water. [abstract], p. 64 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Kanaskie, A., N. Osterbauer, E. Goheen, E. Hansen, M. McWilliams, and W. Sutton. 2002a. Monitoring *Phytophthora ramorum* within and around disease patches targeted for eradication in Oregon. [abstract], p. 39 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Kanaskie, A., K. Violet, E. Hansen, W. Sutton, and J. Labonte. 2002b. Monitoring insect activity near sites infested with *Phytophthora ramorum* in southwest Oregon [abstract], p. 81 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Kanaskie, A., N. Osterbauer, M. McWilliams, E. Goheen, E. Hansen, and W. Sutton. 2004. Eradication of *Phytophthora ramorum* From Oregon Tanoak Forests - Status After Three Years [abstract]. Conference of *Phytophthoras* in Forest and Natural Ecosystems, September 11-17, 2004. International Union of Forest Research Organizations. Retrieved January 13, 2005 from http://www.lwf.uni-muenchen.de/iufro-online/index.html

Kanaskie, A., E. Hansen, W. Sutton and E. Goheen. 2005. Effects of phosphonate treatments on the growth of *Phytophthora ramorum* in tanoak stems. [abstract], p. 48 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Kelly, M. and R. Meentemeyer. 2002. Remote sensing of host species distribution in hardwood forests with sudden oak death in Marin and Sonoma Counties [abstract], p. 26 *in*: Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley. http://danr.ucop.edu/ihrmp/sodsymposium.html.

Kliejunas, J. 2001. Sudden oak death, *Phytophthora* sp. Pest Risk Assessment. U.S. Forest Service.

Kliejunas, J. 2003. A Pest Risk Assessment for *Phytophthora ramorum* in North America. U.S. Forest Service.

Klinger, L. 2002. The ecology of mosses in forest decline [abstract], *in*: Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley. pp. 67-68. http://danr.ucop.edu/ihrmp/sodsymposium.html.

Kong, P. and C. Hong. 2002. Rapid identification of *Phytophthora ramorum* using single strand conformation polymorphism of ribosomal DNA [abstract], p. 57 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley. http://danr.ucop.edu/ihrmp/sodsymposium.html.

Kosta, K. 2002. Survey of co-generation facilities for Sudden Oak Death, and the symptoms of foliar diseases caused by *Phytophthora ramorum*. Report to California Oak Mortality Task Force, October 26, 2002.

Kroon, L. P. N M., E. C. P. Verstappen, L. F. F. Kox, W. G. Flier and P. J. M. Bonants. 2004. A rapid diagnostic test to distinguish between American and European populations of *Phytophthora ramorum*. Phytopathology 94:613-620.

Lane, C. R., P. A. Beales, K. J. D. Hughes, J. A. Tomlinson, A. J. Inman and K. Warwick. 2004. First report of ramorum dieback (*Phytophthora ramorum*) on container-grown English yew (*Taxus baccata*) in England. Plant Pathology 53: 522.

Lewis, C. D., and J. L. Parke. 2005. Pathways for infection for *Phytophthora ramorum* [abstract], p. 68.*in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Levien, L., J. Mai, and W. Mark. 2002. Statewide aerial and ground surveys for mapping and monitoring the distribution of sudden oak death [abstract], p. 27 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Liebold, A. M., MacDonald, W. L. , Bergdahl, D. and V. C. Mastro. 1995. Invasion by exotic forest pests: a threat to forest ecosystems. Forest Science 41 (2): 1-49.

Linderman, R. G., J. L. Parke, and E. M. Hansen. 2002. Relative virulence of *Phytophthora* species, including the sudden oak death pathogen, *P. ramorum*, on leaves of several ornamentals [abstract], p. 82 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Linderman, R. G., and E. A. Davis. 2005. Survival of *Phytophthora* species and other pathogens in soilless media components or soil and their eradication with aerated stem. [abstract], p. 70 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Livingston, M. 2003. USDA-APHIS Regulatory Flexibility Analysis in APHIS' Eradication and Control Programs by Kevin Shea in Invasive Species Management Workshop on the Economics of Invasive Species, May 12-13, 2003. Retrieved January 13, 2005 from http://www.ers.usda.gov/Briefing/InvasiveSpecies/Data/Shea_v2.pdf

Mabberly, D. J. 1997. The Plant-Book: A Portable Dictionary of the Vascular Plants, 2ed. Cambridge, U.K.: Cambridge University Press. 858pp

Magarey, R., L. Garrett, and G. Fowler. 2004. Risk Model for *Phytophthora ramorum* (Sudden Oak Death) in Nursery Shipments. *Phytophthora ramorum* Science Panel, Center for Plant Health Science and Technology, June 29-30, 2004, Raleigh, NC.

Magnusson, C., B. Okland and H. Solheim. 2001. Wood Chips. In: Risks of Exotic Forest Pests and Their Impact on Trade. An International Online Workshop to Reduce Movement of Forest Pests with a Minimal Impact on Trade. Retrieved January 13, 2005 from http://www.aspnet.org/online/ExoticPest/Index.html

Maloney, P. E., S. F. Kane, C. E. Jensen, and D. M Rizzo. 2002a. Epidemiology and ecology of *Phytophthora ramorum* in redwood/tanoak forest ecosystems of the California coast range [abstract], p. 11 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Maloney, P. E., S. F. Kane, C. E. Jensen, and D. M. Rizzo. 2002b. Studies on the effect of *Phytophthora ramorum* on madrone [abstract], pp. 82-83 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html.

Maloney, P. E., D. M. Rizzo, S. T. Koike, T. Y Harnik, and M. Garbelotto. 2002c. First report of *Phytophthora ramorum* on coast redwood in California. Plant Dis. 86: 1274.

Maloney, P. E., S. C. Lynch, S. F. Kane, and D. M. Rizzo. 2004 Disease progression of Phytophthora ramorum and Botryosphaeria dothidea on Pacific madrone. Plant Dis. 88: 852-857.

Man in't Veld, W., H. de Gruyter, P. J. M. Bonants, and R. P. Baayen. 2002. Isozyme genotyping of *Phytophthora ramorum* reveals a remarkable homogeneity [abstract], pp. 58-59 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Martin, F. N. and P. Tooley. 2001. Molecular phylogeny of *Phytophthora* based on mitochondrial gene sequences. American Phytopathology Society 91: S58.

Martin, F. N, P. W. Tooley, and R. Fredrick. 2002. The Use of mitochondrial molecular markers for identification of *P. ramorum* [abstract], p. 18 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

McGregor, B. M. 1987. Tropical Products Transport Handbook. United States Department of Agriculture, Office of Transportation, Agriculture Handbook. No. 668. 148 pp.

Meentemeyer, R., H. Cushman, J. Christmann, N. Rank, R. Whitkus, and D. Rizzo. 2002. Modeling of the spread of *Phytophthora ramorum:* Integrating spatial data on abiotic conditions, plant community structure, and population genetics of host species [abstract], pp. 49-50 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Meentemeyer, R. and M. Kelly. 2002. Spacial modeling of sudden oak death risk and oak mortality clustering, China Camp State Park [abstract], p. 25 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Menge, J. A. and S. Nemec. 1997. Citrus. *in* R. J. Hillocks and J. M. Walker (eds.), Soilborne Diseases of Tropical Crops,. CAB International.

Meshriy, M., Hüberli, D., Tamar, H., Miles, L. Reuther, K. and M. Garbelotto. 2005. Variation in susceptibility of *Umbellularia californica* (bay laurel) to *Phytophthora ramorum*. [abstract], p. 31 *in*: Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Moralejo, E. and L. Hernandez. 2002. Inoculation trials of *Phytophthora ramorum* on detached Mediterranean sclerophyll leaves [abstract], p. 32. *in* Proceedings of Sudden Oak Death, a Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

McDonald, J. D., J. Stites, and J. Kabashima. 1990. Comparison of serological and culture plate methods for detecting species of *Phytophthora*, *Pythium*, and *Rhizoctonia* in ornamental plants. Plant Disease 74: 655-659.

McPherson, B. A., D. L. Wood, A. J. Storer, P. Svihra, D. M. Rizzo, N. M. Kelly, R. B. Standiford. 2000. Oak Mortality Syndrome: Sudden Death of Oaks and Tanoaks. California Department of Forestry and Fire Protection. Tree Notes 26: 1-6.

McPherson, B. A., R. B. Standiford, D. L. Wood, A. J. Storer, and P. Svihra. 2002a. Interactions among bark and ambrosia beetles (Coleoptera: Scolytidae) and a novel disease of oaks in California [abstract], pp.68-69 *in* Proceedings of Sudden Oak Death, A Science Symposium,

USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

McPherson, B. A., D. L. Wood, A. J. Storer, and R. B. Standiford. 2002b. Plant progression of sudden oak death over two years at sites in Marin County, California [abstract], p. 12 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Murphy. S. K., and D. M. Rizzo. 2003. First report of *Phytophthora ramorum* on Canyon Live Oak in California. Plant Disease 87: 315.

Murphy, S. K., J. Bienapfl, D. M. Rizzo, Y. Valachovic, and C. Lee. 2005. Monitoring *Phytophthora ramorum* distribution in streams within Coastal California watersheds [abstr.], p. 108. *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

NAPPO. 2004. Glossary of Phytosanitary Terms. RSMP No. 5. The Secretariat of the North American Plant Protection Organization. Retrieved March 14, 2005 from http://www.nappo.org/Standards/REVIEW/RSPM5-e.pdf

NASS. 2004. Floriculture and Nursery Crops Situation and Outlook Yearbook. United States Department of Agriculture. Economic Research Service FLO-2004. June, 2004.

Nixon, K. C. 2002. The Oak (*Quercus*) Biodiversity of California and Adjacent Regions. USDA Forest Service Gen. Tech. Rep. PSW-GTR-184.

OASS. 2004. Oregon Christmas Tree Survey – 2003. Oregon Agricultural Statistics Service. U.S. Department of Agriculture. Retrieved March 17, 2004 from http://www.nass.usda.gov/or/Christmastreerelease2003.pdf

ODA. 2001. Quarantine Regulation. Oregon Department of Agriculture. Retrieved April 1, 2005 from http://www.oda.state.or.us/plant/ppd/path/SOD/SOD_quar.html

OS0S. 2004. Oregon Department of Agriculture Emergency Quarantine Order: Columbia County Nursery Stock, Potting Media and Compost. Oregon Bulletin, July 1, 2004. Oregon Secretary of State (OSOS). Retrieved March 17, 2005 from http://arcweb.sos.state.or.us/rules/0704_Bulletin/0704_othnotices_bulletin.html

Osterbauer, N. K. 2003. *Phytophthora ramorum* Werres, de Cock & Man in't Veld. Pest risk assessment for Oregon. Retrieved December 3, 2004 from http://oda.state.or.us/plant/ppd/path/SOD/SOD_PRA_Oregon_2=03.pdf

Osterbauer, N. K., L. Rehms, and J. Hedberg. 2002. Survey of Oregon nurseries and other commodities for *Phytophthora ramorum* [abstract], p.90 *in*:Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Parke, J. L., E. M Hansen, and R. G. Linderman. 2002a. Sporulation potential of *Phytophthora ramorum* on leaf disks from selected hosts [abstract], p. 33 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Parke, J. L., R. G. Linderman, and E. M. Hansen. 2002b. Assessing the susceptibility of Pacific Northwest nursery plants to *Phytophthora ramorum* using a detached leaf assay [abstract], pp.84-85 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html.

Parke, J. L., R. G. Linderman, K. Hummer, and E. M. Hansen. 2002c. Differential susceptibility to *Phytophthora ramorum* among *Vaccinium* species and cultivars [abstract], pp.83-84 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Parke, J., J. Pscheidt and R. Linderman. 2003. *Phytophthora ramorum* – A guide for Oregon nurseries. Dept. of Botany and Plant Pathology, Oregon State University Extension. EM 8840. 8 pp. Retrieved March 22, 2005 from http://www.suddenoakdeath.org/

Parke, J. L., R. G. Linderman, N. Osterbauer, and J. A. Griesbach. 2004a. Detection of *Phytophthora ramorum* blight in Oregon nurseries and completion of Koch's Postulates on *Pieris, Rhododendron, Viburnum* and *Camellia*. Plant Disease 88: 87.

Parke, J., J. Pscheidt and R. Linderman. 2004b. *Phytophthora ramorum* – A guide for Washington nurseries. Dept. of Botany and Plant Pathology, Oregon State University Extension Service. 8 pp. Retrieved March 22, 2005from http://www.suddenoakdeath.org/

Parke, J. L., M. L. Roth, and C. J. Choquette. 2005a. Detached leaf assays with *Phytophthora ramorum:* Are they valid? [abstract], p. 110 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Parke, J. L., M. L. Roth, and C. J. Choquette. 2005b. *Phytophthora ramorum* disease transmission from infested potting media. [abstract], p. 66 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Pogoda, F. and S. Werres. 2002. Pathogenicity of European and American *Phytophthora ramorum* isolates to *Rhododendron* [abstract], p.85 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Pogoda, F. and S. Werres. 2004. Histological studies of *Phytophthora ramorum* in *Rhododendron* twigs. Can. J. Bot. **82**: 1481–1489. doi: 10.1139/B04-104.

PPQ. 2005. PPQ *P. ramorum* Science Panel Workshop. Plant Protection and Quarantine. Updated March 4, 2005. Retrieved March 28, 2005 from http://www.aphis.usda.gov/ppq/ispm/pramorum/sciencepanel.html

Prospero, S. E. M. Hansen, and L. M. Winton. 2005. Genetic uniformity of *Phytophthora ramorum* in North American forests revealed by microsatellite markers, p. 111 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Ristaino, J. B., and M. L. Gumpertz. 2000. New frontiers in the study of dispersal and spatial analysis of epidemics caused by species in the genus *Phytophthora*. Annual Review of Phytopathology 38: 541-76.

Rizzo, D. M., M. Garbelotto, J. M. Davidson, G. W. Slaughter and S. T. Koike. 2001. A new *Phytophthora* canker disease as the probable cause of Sudden Oak Death in California. Phytopathology 91: S76.

Rizzo, D. M., M. Garbelotto, J. M. Davidson, G. W. Slaughter, and S. T. Koike. 2002a. *Phytophthora ramorum* and sudden oak death in California: I. Host relationships *in* R. Standiford and D. McCreary (eds.) 5th symposium on California Oak Woodlands. USDA Forest Service Gen. Tech. Rep. PSW-GTR-184. pp. 733-740.

Rizzo, D. M., M. Garbelotto, J. M. Davidson, G.W. Slaughter, and S.T. Koike. 2002b. *Phytophthora ramorum* as the cause of Extensive Mortality of Quercus spp. and *Lithocarpus densiflorus* in California. Plant Disease 86: 205-214.

Rizzo, D. M., and M. Garbelotto. 2003. Sudden Oak Death: endangering California and Oregon forest ecosystems. Front. Ecol. Environ 1(5): 197-204.

Rizzo, D. M., M. Garbelotto, and E. M. Hansen. 2005. *Phytophthora ramorum*: Integrative research and management of an emerging pathogen in California and Oregon forests. Annu. Rev. Phytopathol. 43: 13.1-3.27.

Schmidt, D., T. Harnik, D. Rizzo and M. Garbelotto. 2002. Chemical Treatment Strategies for control of Sudden Oak Death in Oaks and Tanoaks [abstract], p. 42 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley. from http://danr.ucop.edu/ihrmp/sodsymposium.html

Schmidt, D., M. Garbelotto, D. Chambers, and S. Tjosvold. 2005. Effect of phosphonate treatments on sudden oak death in tanoak and Shreve's oak. [abstract], p. 50 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Shelly, J, W. Tietje, and D. McCreary. 1996. Resource Evaluation for Forest Products. Chapter 8. IN Guidelines for Managing California's Hardwood Rangelands. University of California Division of Agriculture and Natural Resources Publication 3368. Oakland, CA. pp. 82-97.

Shelly, J., R., Singh, C. Langford, and T. Mason. 2005a. Evaluating the survival of *Phytophthora ramorum* in firewood. [abstract], p. 112 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Shelly, J., R., Singh, C. Langford, and T. Mason. 2005b. Understanding the disposal and utilization options for sudden oak death – diseased wood. [abstract], p. 86 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Shurtleff, M. C, and C. W. Averre. 1997. Glossary of Plant-Pathological Terms. St. Paul, MN: APS Press. 361 pp.

Smart, C. and W. Fry. 2001. Invasions by the late blight pathogen: renewed sex and enhanced fitness. Biological Invasions 3: 235–243.

Smith, W. D., E. M. Goheen, F. Sapio, K. W. Gottschalk, S. Frankel, and P. Dunn. 2002. Development of a National Survey Protocol for Detection of *Phytophthora ramorum.* [abstract], p. 24 *in* Proceedings of the Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Stipes, R. J. and R. J. Campana, (eds.). 1981. Compendium of Elm Diseases. St. Paul, MN: APS Press. 96 pp.

Storer, A. J., K. E. Keirnan, N. K. Palkovsky, B. W. Hagen, G. W. Slaughter, N. M. Kelly and P. Svihra. 2002. Sudden Oak Death: Diagnosis and Management. University of California, Cooperative Extension in Marin County. Pest Alert #6: 1-12.

Suslow, K., K. Kosta, G. Raabe, and S. Cohen. 2004. Best Management Practices for the California Nursery Industry for Sudden Oak Death (SOD) Biosecurity (Revised 10-20-03; K. Suslow, K. Kosta, G. Raabe, S. Cohen) (Draft Revision 5-04 K. Suslow). Nursery Committee of the California Oak Mortality Task Force. Retrieved February 16, 2005 http://www.suddenoakdeath.org/pdf/NurseryBMPs5.04.pdf

Swain, S., T. Harnick, M. Mejia-Chang, J. Creque, and M. Garbelotto. 2002. Survivability of *Phytophthora ramorum* in the composting process [abstract], p.44 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Swain, S., T. Harnick, M. Mejia-Chang, K. Hayden, W. Bakx, J. Creque, and M. Garbelotto. 2003. Heat and composing effects of the viability of *Phytophthora ramorum* when grown on a variety of artificial and plant substrates. Rprt.

Swain, S. and M. Garbelotto. 2005. Potential for re-infection of finished compost by *Phytophthora ramorum*. [abstract], p.88 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Swain, S., T. Harnick, M. Mejia-Chang, K. Hayden, W. Bakx, J. Creque, and M. Garbelotto. 2005. Heat and composing effects of the viability of *Phytophthora ramorum*, when grown on a variety of artificial and plant substrates. Final Report. University of California, Berkeley from http://www.cnr.berkeley.edu/garbelotto/downloads/compostreport05.pdf

Swiecki, T. J. and E. A. Bernhardt. 2002a. Factors related to Phytophthora canker (sudden oak death) disease risk and disease progress in coast live oak and tanoak. Report for USDA Forest Service, Phytosphere Research Project No. 2001-0802, July 28, 2002

Swiecki, T. J. and E. A. Bernhardt. 2002b. Evaluation of stem water potential and other tree and stand variables as risk factors for *Phytophthora ramorum* canker development in coast live oak, *in* R. Standiford and D. McCreary (eds.) 5th Symposium on California Oak Woodlands. USDA Forest Service, Gen. Tech. Rep. PSW-GTR-184, p. 787-798.

Tjosvold, S. A., D.L. Chambers, J. Tse, J. M. Davidson, M. Garbelotto, and D. M. Rizzo. 2002a. Evaluation of a novel diagnostic procedure to detect the presence of *Phytophthora ramorum* by sampling ooze from infected cankers [abstract], pp. 91-92 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Tjosvold, S. A., D. L. Chambers, J. M. Davidson, and D. M. Rizzo. 2002b. Incidence of *Phytophthora ramorum* Inoculum Found in Soil Collected from a Hiking Trail and Hikers' Shoes in a California Park [abstract], p. 53 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Tjosvold, S. A., D. L. Chambers, J. M. Davidson, and D.M. Rizzo. 2002c. Incidence of *Phytophthora ramorum* Inoculum Found in Streams Running through Areas of High Incidence of Sudden Oak Death in Santa Cruz County [abstract], pp. 52-53 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Tjosvold, S.A., S.T. Koike, J.M. Davidson, and D.M. Rizzo. 2002d. Susceptibility of Azalea *(Rhododendron)* to *Phytophthora ramorum* [abstract], p. 86 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley. from http://danr.ucop.edu/ihrmp/sodsymposium.html

Tjosvold, S. A., K. R. Buermeyer, C. Blomquist, and S. Frankel. 2004. Guide to Diseases of *Phytophthora ramorum* in Ornamental Nurseries, Diagnosis and Management. Draft, October 2004. Retrieved March 22, 2005 from http://www.suddenoakdeath.org/

Tjosvold, S. A., D. L. Chambers, & S. T. Koike. 2005. Evaluation of fungicides for the control of *Phytophthora ramorum* infecting *Rhododendron, Camellia, Viburnum* and *Pieris*. [abstract], p. 55 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

Tooley, P. W. and K. L. Kyde. 2003. Susceptibility of some eastern oak species to sudden oak death caused by *Phytophthora ramorum*. Phytopathology 93: S84.

Tooley, P. W., K. L. Kyde, and L. Englander 2004. Susceptibility of selected Ericaceous ornamental host species to *Phytophthora ramorum*. Plant Dis. 88: 993-999.

Trent, A. and D. Karsky. 2002. Use of Power Washer for Sudden Oak Death Mitigation [abstract], pp.74-75 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Turner, J., P. Jennings, S. McDonough, D. Liddell and J. Stonehouse. 2005. Chemical control of *Phytophthora ramorum* causing foliar disease in hardy nursery stock in the UK. [abstract], p. 56 *in* Sudden Oak Death Second Science Symposium The State of our Knowledge. January 18-21, 2005, Monterey, California.

USBC. 1998. Statistical Abstract of the United States 1996. 200th ed. Washington, DC: U.S. Bureau of the Census, U.S. Government Printing Office.

USDA. 2003. USDA Plant Hardiness Zone Map. USDA Miscellaneous Publication No. 1475, Issued January 1990. Retrieved February 28, 2005 from http://www.usna.usda.gov/Hardzone/ushzmap.html

USITC. 2005. Interactive Tariff and Trade Dataweb. United States International Trade Commission. Retrieved February 10, 2005 from http://dataweb.usitc.gov

Vanderplank, J.E. 1963. Plant Diseases: Epidemics and Control. New York: Academic Press. 349 p.

Varela, P. J. P. Mansilla Vazquez, and O. Aguín Casa. 2003. First report of *Phytophthora ramorum* on *Camellia japonica* in Spain. Plant Disease 87: 1396.

Von Broemsben, S. 1999. Disease management for nurseries using recycling irrigation systems. Retrieved March 28, 2005 from http://entoplp.okstate.edu/zoospore/index.html

Werres, S., R. Marwitz, WA. Man In ‘T Veld, A. W. A. M. De Cock, P. J. M. Bonants, M. De Weerdt, K. Themann, E. Ilieva and R. P. Baayen. 2001. *Phytophthora ramorum sp. nov*., a new pathogen on *Rhododendron* and *Viburnum*. Mycological Research 105: 1155-1165.

Werres, S. and D. De Merlier. 2003. First detection of *Phytophthora ramorum* mating type A2 in Europe. Plant Disease 87: 1266.

Werres, S. and B. Ziekle. 2003. First studies on the pairing of *Phytophthora ramorum.* Zietschrift für Plfanzenkrankheiten und Plfanzenschutz 110(2): 120-130.

Wilhem, S., and A. O. Paulus. 1980. How soil fumigation benefits the California strawberry industry. Plant Dis. 64.264-270.

Yeager, T., C. Gilliam, T. Bilderback, D. Fare, A. Niemiera and K. Tilt. 1997. Best Management Practices: Guide for Producing Container Grown Plants. Marietta, GA: South. Nurs. Assoc. 69 pp.

Zanzot, J. W., J. L. Parke, and E. M. Hansen. 2002. Potential Susceptibility of Native Southwest Oregon Plant Species to *Phytophthora ramorum* [abstract], p. 34 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html

Zanzot, J. W., J. L. Parke, and E. M. Hansen. 2003. Potential for *Phytophthora ramorum* to infect tanoak-associated vegetation in southwestern Oregon. Phytopathology 93: S93.

Zielke, B. and S. Werres. 2002. Taxonomic investigations of European and American isolates of *Phytophthora ramorum* [abstract], pp. 59-60 *in* Proceedings of Sudden Oak Death, A Science Symposium, USDA Forest Service and University of California, Berkeley from http://danr.ucop.edu/ihrmp/sodsymposium.html