DRAFT:09/13/09

Economic and Environmental Impacts of *Phytophthora ramorum* – Literature Review Completed Through August, 2009

Introduction

The introduction and establishment of the exotic pathogen *Phytophthora ramorum* into native forest ecosystems of California and Oregon, into the nursery/ornamental trade of the United States (U.S.), Canada and Europe, and into European gardens and landscapes have had significant economic and environmental impacts. Establishment of the pathogen in areas such as the hardwood forests of the eastern United States where known susceptible hosts occur will have additional impacts.

This chapter is not intended to be an economic analysis, but rather summarizes the literature on the economic and environmental impacts of *P. ramorum*. The economic impacts section discusses the resources at risk (benefits of hosts/products) and the costs of *P. ramorum* in forests and woodlands, urban forests, and Christmas tree plantations; on forest products other than timber, and other forest values; in the nursery industry, and in the cut flower and foliage industry. The environmental impacts section summarizes the literature on the benefits provided by ecosystems and the effects of *P. ramorum* (potential for ecosystem destabilization, reduction in biodiversity, reduction or elimination of keystone species, reduction or elimination of endangered or threatened species), on recreation, and on wildlife.

Economic Impacts

Forests/Woodlands, U.S.

Resources at Risk: California oak woodlands contain about 5 billion cubic feet of wood with a stumpage value over $275 million (Kliejunas 2003). The 5.8 billion cubic feet of oaks in nearby California timberlands 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). In the U.S. as a whole, the export market value of red oak logs and lumber in 2002 was over $300 million (USITC 2005).

In Oregon, the annual timber harvest value (mostly Douglas-fir [*Pseudotsuga menziesii*]) of the four southwest Oregon counties (Josephine, Coos, Curry, and Douglas) where tanoak occurs,

based on 2006 data, is $1.68 billion per year (Kanaskie and others 2008b). Although neither tanoak (*Lithocarpus densiflorus*) nor coast live oak (*Quercus agrifolia*) is a commercial timber tree in California or Oregon, tanoak is harvested in Oregon for the chip market when prices warrant.

Costs: The major impact of *P. ramorum* in forests of the U.S. has occurred in the mixed evergreen and redwood-tanoak forests of coastal central California. Although damage on coast redwood and Douglas-fir from *P. ramorum* is limited to foliage and small branches, regulatory actions to prevent spread of the pathogen (for example, requiring removal of small branches, washing logs of soil) could impact (presumably in the form of lost markets) the redwood and Douglas-fir industry in California at an estimated $50 million a year (USDA 2005). As an example, 2009 was the first year in over 20 years with an abundant redwood (*Sequoia sempervirens*) cone crop. Seed collections costs were increased by the need to comply with *P. ramorum* regulations that prohibit movement of redwood twigs and needles from moving out of the infested coastal California counties. Every cone had to be clipped by hand, costing an estimated $100 per bushel for the 300 bushels collected (Susan Frankel, SOD program manager, 2009, personal communication) Any regulations imposed to limit spread may also affect timber harvest and trade in the commercial Douglas-fir forests in Oregon, Washington, and western Canada.

Figure 1. *Phytophthora ramorum* symptoms on coast redwood. Photo by Garbelotto lab, University of California, Berkeley.

In Oregon, potential losses of at least $100 million per year in stumpage value (lost harvest) are estimated if eradication is not successful and *P. ramorum* spreads uncontrolled in southwest Oregon (Kanaskie and others 2008b). Between 2001 and the end of 2008, eradication treatments in Curry County, Oregon were completed on approximately 2,400 acres of forest at a cost of $4.3 million (Kanaskie and others 2008a; Kanaskie and others unpublished). Additional costs to monitor and manage the eradication program (environmental documentation for treatment for example) have incurred.

An economic analysis of three control scenarios in Oregon forests—continue the current control program (removal and destruction of all host plants within a 100 m radius when monitoring discovers an infected plant), increase the control program in an attempt to eradicate the pathogen from Oregon forests within 5 years (increase the level of monitoring and control), and no control program (monitoring only) was performed (Hall and Albers 2009). The analysis assumed that each policy would affect costs by altering the rate of spread of the pathogen and thus determine the rate of increase in the quarantine area. Costs to agencies as a result of program implementa-

tion and costs to the forest products industry as a result of *P. ramorum* quarantine regulation were projected out for 20 years under the three scenarios. A variety of other costs (a reduction in Oregon's forest product export market, a reduction in the non-timber forest product market, and increased production costs for producers utilizing *P. ramorum* host plants) were not included. The estimated costs and benefits associated with each program are summarized in Table 1. The wide range in benefit estimates (from a negative $6 to $9 million to a positive $1.2 billion) results from basing the estimates largely on the uncertain spread rate of *P. ramorum* in Oregon forests.

Table 1. Summary of costs and benefits associated with control programs in Oregon forests

Control Program	Cost (millions)	Benefit (millions)
None	$21.3to $1,238.5	$0
Current	$27.5to $33.4	-$6.2to $1,205.1
Eradication	$30.4 to $31.5	-$9,079.0 to $1,207.0

The economic value of eastern U.S. timber species would be significantly reduced if *P. ramorum* becomes established there. Two oak species (*Quercus rubra* and *Q. falcata*) native to the eastern U.S. were found naturally infected in Europe (Brasier and others 2004, EPPO 2004), and susceptibility of other eastern U.S. tree species (*Q. alba*, *Q. laurifolia*, *Q. nigra*, *Q. pagoda*, *Q. phellos*, *Q. prinus*, *Q. virginiana*, *Acer saccharum*, Juglans nigra) has been experimentally demonstrated (Brasier and others 2005, Linderman and others 2007, Tooley and Kyde 2007). The potential economic threat from the pathogen to commercial timber production from oak hardwood forests in the U.S. has been estimated as exceeding $30 billion (Kliejunas 2003).

The pathogen has affected international trade. Numerous countries have placed restrictions on the movement of affected plants and plant parts from the U.S. (Rizzo and Garbelotto 2003, EXCERPT 2007), thus reducing potential markets for forest hosts of *P. ramorum*. Worldwide, the Euopean Union (EU) pest risk analysis for *P. ramorum* (Sansford and others 2009) lists 68 countries (Appendix IV) for which *P. ramorum* is either on their lists of regulated pests or mentioned in their legislation.

Forests/Woodlands, Canada and Europe

To date, no tree species have become affected in woodlands or forests in Canada, and no timber plantations have become affected in the EU. Because widespread mortality in forests in Canada, the United Kingdom (U.K.) and the EU has not occurred, potential economic losses due to *P. ramorum* have not been quantitatively estimated. The estimated annual value of timber in the

U.K. is (in 2003 figures) about £36 million (Woodhall and Sansford 2007). Kehlenbeck (2008) estimated that in the "Northern European Tree Host System" (broadly-defined as trees with stem cankers in association with infected rhododendron in the Netherlands and the U.K.) present impacts are moderate and restricted to few areas where *Rhododendron* are associated with tree hosts and environmental impact is caused. Kehlenbeck (2008) estimated the potential impact to be not more than moderate where no widely distributed foliar hosts of Northern European forests occur. In the "Southern European Tree Host System" present impacts are minimal, but potential impact is predicted to be major if *P. ramorum* would be introduced and spread in the unique Mediterranean laurel and *Q. ilex* forests (Sansford and others 2009).

If *P. ramorum* became established in timber plantations in the EU there is a potential risk of tree death of a range of species including beech (*Fagus sylvatica*) and oak (*Quercus* spp.), as trees of these species have died in the U.K. and the Netherlands. Based on climatic conditions most similar to California and Oregon, the areas most likely to become affected are northwest Spain, northern Portugal, south-west England, and parts of Italy and western Albania. The long term impact was estimated to be minor to moderate in the absence of controls (Sansford and others 2009).

The U.K. has provided £25 million for a five year program (2009 to 2014) to contain and eradicate *P. ramorum* and *Phytophthora kernoviae* in historic gardens, woodlands, heathlands and from nurseries and retailers in England and Wales. As part of that program, a control strategy for *P. ramorum* will include removal of the sporulating host *Rhododendron ponticum* from woodlands, heathlands and public gardens. Based on work in Cornwall, U.K., the costs of clearance for *R. ponticum* (as a control strategy for both *P. ramorum* and *P. kernoviae*) are estimated at £7,000 per ha for woodland and £10,000 per ha for public gardens (I. Sanders, PHSI, personal communication, 2007; as cited in Sansford and others 2009). However, in some situations removal is seen as a benefit, as it would lead to an increase in biodiversity of woodlands and heathlands. Sansford and others (2009) present an analysis indicating that the biodiversity benefits from undertaking clearance of understory *R. ponticum* for disease control is £3 million over 20 years. Removal of *R. ponticum* from heathlands is also seen as a benefit because biodiversity and heathland condition would improve. Sansford and others (2009) calculated a benefit (as a reduction in heathland loss) of £20,000 over 20 years.

Urban Forests

Resources at Risk: In coastal central California, the value of 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 southwestern Oregon, mature black oak trees can increase property values by $5,000 to $30,000 (Osterbauer 2003).

Costs: Kovacs and others (unpublished data)[1] found a decrease in property values in the north Bay Area (Marin County) of California with proximity to areas affected by *P. ramorum* (proximity to oak woodlands, confirmed infections, aerial observed oak mortality, or arborist reported oak mortality). They found a 2 to 5 percent lower value for properties within a quarter mile of oak woodlands infested with *P. ramorum*, and a 5 to 8 percent lower value for properties with confirmed infected trees; the property value rebounds when infected trees are removed.

Tree mortality resulting from *P. ramorum* increases risk from tree failure and more intensive fires due to increased fuel loads from dead trees. In California, landowners in the infested areas have to pay for the costly removal of dead trees to protect homes and property. Kovacs and others (see footnote 1) estimated a removal and treatment cost of $20.5 million over a 10 year period (1998 to 2007) in urban areas of Marin County, California. A survey of arborists in Marin County, California, found that the average cost of oak tree removal was $1,700 per tree; average cost of pruning or removal of California bay trees was $600 (see footnote 1). In Oregon, the cost for removal of a single dead tree from a homeowner's property was as high as $3,000 (Osterbauer 2003). Economic losses from removal of infected Quercus trees may be partially offset by utilization of the material for wood products (Shelly and others 1996).

Figure 2. Coast live oak mortality circa 2001 in the wildlife-urban interface in San Rafael, California. Photo by Marin County Fire Department.

Two small (less than 1 ha) fires (one in Napa County and one in Sonoma County) have been caused by dead trees (*P. ramorum*-infected) snapping and hitting power lines (Frankel 2008). Power company cost of dead tree removal to prevent power line damage is extremely variable depending on accessibility, tree size and other factors. Estimates in the Big Sur region of coastal central California begin at about $600 per tree. During a 3 year period (April 2002 through March 2005), the State of California spent $1.5 million on hazard tree removal in five *P. ramorum*-infested counties (Marin, Sonoma, Alameda, Santa Cruz, and Monterey). Additional costs of the hazard tree program included $205,000 for hazard tree assessment and about $71,000 for restoration (Stephen Jones, CalFire, 2009, personal communication). In 2009, the Santa Clara Fire Safe Council received a $150,000 grant for removal of hazard trees resulting from *P. ramorum*-caused mortality (San Jose Mercury News 2009).

[1] K. Kovacs, University of Nevada, Reno; J. Englin, University of Nevada, Reno; T. Holmes, USDA FS, Southern Research Station, Research Triangle Park; J. Alexander, UC Cooperative Extension, Marin County.

Preventive treatments of oaks in urban areas with the systemic fungicide Agri-fos® are expensive as well as potentially harmful to the environment if used incorrectly. A limited survey of arborists in Marin County, California found 1,400 customers with treatments in the seven companies surveyed, at an average cost of $115 per treatment (see footnote 1). The current recommendation is for reapplication each year so these costs to homeowners (but benefits to arborist companies) may accumulate over time.

A strategic plan for Sonoma County, California (Bell and others 2008) summarizes needed funds for an effective *P. ramorum* management program in the first and subsequent years (Table 2). Estimated costs are for hazardous tree management, slow the spread practices, education of agencies and publics, and fuels reduction in the urban/wildland interface.

Table 2. Summary of needs and costs, *Phytophthora ramorum* management in Sonoma County, California

Anticipated Needs	Estimated Costs (thousands)	
	Year 1	Subsequent Years
Fire fuels reduction/mitigation	$2,000.0	$2,060.0
Tree removal and treatment/forest health	$867.1	$639.1
Education and outreach	$313.1	$296.1
Develop fuel model	$200.0	0
Hazardous and infected tree survey	$614.2	$122.6
Staff training	$36.5	$37,6
Develop SOD protocols	$30.0	0
Fire fuels survey and mitigation plan	$30.0	0
Fire department funds	$16.16	$16,2
Total	$4,107.1	$3,171.6

Christmas Tree Plantations

Resources at Risk: Nationwide, the Christmas tree industry had a wholesale value of $520 million in 2003 (Jerado 2004, Cave and others 2005). Of that value, Oregon produced $158 million, Washington $60 million, and California $10.4 million (Jerado 2004, USDA 2005).

Costs: Expansion of establishment of *P. ramorum* in the industry and resulting regulation on trade would likely have significant, but unknown, economic impact. A major Christmas tree species, Douglas-fir, is a host of *P. ramorum*. Other Christmas tree species have been found naturally infected (grand fir [*Abies grandis*], white fir [*A. concolor*], red fir [*A. magnifica*]) or susceptible in laboratory trials (Chastagner and others 2004). The pathogen has been detected in

Christmas tree plantations in the infested area of California, but primarily only in the vicinity of infected California bay laurel (*Umbellularia californica*) or other sporulating hosts (Chastagner and others 2008b). In one instance, Chastagner and others (2008a) found infection of a few white fir and Douglas-fir Christmas trees under a black walnut (*Juglans nigra*) tree that was infected with mistletoe (*Phoradendron serotinum* subsp. *macrophyllum*); the mistletoe was a host of *P. ramorum*. However, their data (Chastagner and others 2008b, 2008c) and the inability of *P. ramorum* to spread from conifer to conifer suggest that there is a very low risk of *P. ramorum* developing in Christmas tree plantations that are not associated with infected high inoculum producing plants, such as California bay laurel. Regulating small branches and twigs of affected species essentially limits movement of host Christmas trees out of regulated areas.

Forest Products Other Than Timber

Resources at Risk: Products crafted from native materials in coastal California, Oregon and Washington forests are economically significant. High value uses for hardwood hosts of *P. ramorum* include custom furniture, flooring, cooperage and tool handles (Shelly and others 1996). Other uses for wood from hardwood hosts include firewood, wood chips for pulping, mulch, compost, non-grade lumber, and charcoal (Cave and others 2007). In 2000, the Chetco Ranger District on the Rogue River-Siskiyou National Forest in Oregon sold permits for 114,500 pounds of tanoak boughs, 18,500 pounds of huckleberry (*Vaccinium* spp.) foliage, 11,000 pounds of madrone (*Arbutus menziesii*) boughs, 100 huckleberry transplants, and about 110,000 pounds of miscellaneous boughs and foliage (Gilbert Zepeda, District Ranger, personal communication, 2001). The foliage of evergreen huckleberry (*Vaccinium ovatum*), used as browse by elk, is harvested for use in floral arrangements. In the 1970s, an estimated $1 million worth of foliage was harvested annually in western Washington (Minore 1972). Huckleberries are an important secondary forest product from Pacific Northwest forests. Volume harvested varies. The wholesale price of huckleberries (includes species in addition to *V. ovatum*) varied from $2.98 to $2.19 per pound in 1995 and 1996 (Osterbauer 2003).

Costs: The economic impacts of *P. ramorum* on forest products other than timber have not been estimated.

Other Forest Values

Other benefits of forests, such as water and watershed protection, grazing, wildlife food and habitat, and recreation (Thomas 1997) are usually considered environmental benefits rather than economical, and are discussed in that section.

Nursery Industry, U.S.

Resources at Risk: In 2006, the U.S. domestic production of nursery crops was valued at about $12.9 billion. Imports for these crops were $341 million and exports were $287 million (Jerado 2007, as cited in Cave and others 2007). The U.S. ornamental nursery industry is valued at over $13 billion annually, ranking as the third highest value crop in the U.S. California is the industry's leading producer of horticultural plants, valued at $2 billion a year. Oregon's industry is ranked fifth nationally and ranks second in the production of woody plants (USDA 2005). In 2006, the wholesale value of nursery stock sold in Oregon was $966 million (NASS 2006).

Figure 3. Quarantined nursery stock. Photo by Shane Sela, Canadian Food Inspection Agency.

Costs: The U.S. nursery industry has been strongly affected by *P. ramorum*. Surveys in March 2004 detected *P. ramorum* in two large southern California nurseries that had shipped potentially infected plants to over 1200 nurseries in 29 states. This finding led to 15 states imposing quarantines on nursery stock from California, resulting in estimated losses of $4.3 million to the nursery industry in California in the first month alone (Frankel, 2008). The California Association of Nurseries and Garden Centers estimated that California nurseries lost $25 million in sales in the spring of 2004 when other states prohibited nursery shipments from California (GAO 2006). In 2004, the United States Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) spent approximately $20 million to trace and destroy all suspect stock from the two nurseries (Frankel 2008). Similar shipments of infested nursery stock, but at a smaller scale, occurred from Oregon and Washington nurseries.

The potential loss to the nursery industry and forests in Oregon from *P. ramorum* was estimated to be between $81 million and $310 million per year (for direct control, management, and regulatory compliance costs plus loss of markets; Anonymous 2008, Griesbach 2008, Kanaskie and others 2008b, Cusak and others 2009). To comply with federal quarantine regulations, the Oregon Department of Agriculture (ODA) has spent about $3.2 million over a 5 year period (2001 through 2006) on surveys of nurseries for *P. ramorum* (Frankel 2008). In 2007, the ODA needed to inspect over 1450 nurseries to comply with the quarantine rules (Frankel 2008).

Some of the financial impacts of *P. ramorum* in the nursery industry result from enforcement of regulations and other disease management practices to control pathogen spread. In fiscal year 2006, USDA APHIS estimated spending approximately $6.35 million in *P. ramorum* nursery activities in California, Washington, and Oregon. Approximately $4.15 million was allocated to inspection, sampling, testing, and certification activities. The remainder of the spending was allocated to national survey, trace forward and trace back investigations, eradication, and regula-

tion enforcement activities (Federal Register 2007). For Oregon nurseries, it was estimated that the cost of inspections and certification would increase from $800,000 to $6.5 million per year if the pathogen became widely established in the state (Griesbach 2008). If the disease became endemic in the Oregon nursery industry, Griesbach (2008) estimated that the annual cost of a prophylactic fungicide program targeted at *P. ramorum* would be $3,960 per acre. Assuming that 10 percent of the 94,250 acres in production in Oregon opt for this treatment, the annual cost to the industry would be $37.3 million; If 25 percent of the acreage is treated, the cost increases to $93.3 million per year.

In addition to the monetary costs of compliance with federal quarantine regulations (compliance agreements and nursery and shipment certifications) borne by the public, the nursery industry has also incurred indirect regulation costs. For example, there could be potential costs associated with lost sales while withholding plants for shipment during inspection and testing (Federal Register 2007). In Oregon, indirect costs due to loss of sales from customer's perception of the product being associated with or exposed to *P. ramorum* range from $34.1 to $204 million per year (Griesbach 2008).

The number and retail value of plants destroyed in Washington State nurseries due to *P. ramorum* quarantine efforts between 2004 and 2005 was estimated by Dart and Chastagner (2007). Data collected during that period indicated that 17,266 containerized nursery plants were destroyed at 32 nurseries, with an estimated retail value of $423,043. The mean loss per nursery was estimated at $11,188 in 2004 and $11,798 in 2005. Other U.S. states do not record this information (Frankel 2008).

The presence of the pathogen within the nursery and ornamental trade has resulted in loss of markets. Oregon ships 75 percent of its nursery production to other states or countries (Griesbach 2008). In 2001, Canada closed its markets to most plant crops from the states of Oregon and California. Without reopened market access, Oregon nurseries alone faced losses in sales to Canada of $15 to $20 million (Canada Gazette 2007, Frankel 2008). For the most part, Canada's markets were reopened to Oregon growers in 2002 (Regelbrugge 2003).

Additional losses to the nursery industry resulting from *P. ramorum* that have not been fully quantified include surveillance and testing costs, facility and equipment cleaning costs, costs of implementation of best management practices such as use of ELISA prescreening tests, and others (Suslow 2006, Frankel 2008, Sansford and others 2009).

Nursery Industry, Canada and Europe

Resources at Risk: In Canada, the value of the British Columbia nursery and floriculture sectors was estimated at $500 million, with approximately $170 million in export sales to the United States (Canada Gazette 2007). Canada's export trade for rhododendrons was valued at $5 million in 2000 (Allen and others 2003).

Costs: Costs to conduct required *P. ramorum* eradication work (plant destruction, soil treatment, loss of plant inventory) in British Columbia nurseries in the spring of 2007 was estimated at $8.5 million. Since then, other nurseries have tested positive for the pathogen which required additional eradication measures (Canada Gazette 2007).

The current impact on nurseries in the EU is considered to be moderate in terms of quality and control costs; including phytosanitary controls, the impact is major (Sansford and others 2009). The potential economic impact for the nursery trade in the EU (27 member states) is estimated as high (Sansford and others 2009).

Cut Flowers/Foliage

Resources at Risk: Cut flower and foliage sales in the U.S. exceeded $406 and $542 million respectively (Jerado 2007, as cited in Cave and others 2007).

Costs: Although the impact of *P. ramorum* to that industry has apparently been minor, Cave and others (2007) point out that there is an increase in flower production from woody ornamentals and many of those plants are hosts for the pathogen, including *Camellia*, *Hamamelis*, *Kalmia*, *Pieris*, *Rhododendron*, *Rosa* and *Syringa* (Bachmann 2002).

Environmental Impacts

The ability or potential of an introduced pathogen such as *P. ramorum* to cause environmental damage by disrupting native forest ecosystems is difficult to predict. The potential for environmental impacts to the nursery industry is equally difficult to estimate. Most literature describing environmental damage simply lists factors of the environment that could be affected, and then describes that environment. Factors typically considered under environmental damage include: potential for ecosystem destabilization, reduction in biodiversity, reduction or elimination of keystone species, reduction or elimination of endangered or threatened species, and nontarget effects of control measures.

The APHIS pest risk assessment for *P. ramorum* (Cave and others 2007) for example, rated the environmental impact of the pathogen as high, 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). A high degree of uncertainty was assigned to the rating because of the difficulty in estimating costs that address all of the relevant ecological components, including: the environmental costs of prevention, eradication or suppression due to herbicide use; the effects on endangered species and the indirect ecological consequences (changes in locally important ecological processes such as perturbations of hydrological cycles such as flood control and water supply, waste assimilation, nutrient recycling, conservation and regeneration of soils, and crop pollination and habitat destruction) (Cave and others 2007).

Figure 4. Tanoak mortality along the Big Sur Coast, California, in 2005. Photo by Dave Rizzo, University of California, Davis.

Ecosystem Effects

Resources at Risk: *Quercus* spp. are considered the most important and widespread of the hardwood trees in the North Temperate Zone, with about 300 species (Pavlik and others 1991). Oak woodlands yield important benefits, including water and watershed protection, grazing, wildlife food and habitat, recreation, and wood products (Thomas 1997, Monahan and Koenig 2006). Oak species are part of forest and savanna woodland ecosystems in Europe and the United States. (Global Invasive Species Database 2006).

Many of the foliar hosts of *P. ramorum* have ecological significance. *Rhododendron* spp. occur worldwide, and some species in the United States are currently listed under the Endangered Species Act. *Vaccinium ovatum*, native to British Columbia, Washington, Oregon and California (Halverson 1986), is a prominent component of California and Oregon forests dominated by tanoak, canyon live oak (*Quercus chrysolepis*) and Pacific madrone (*Arbutus menziesii*) (Sawyer and others 1977). Evergreen huckleberry is an important browse species for elk in the Coast Range and in southern Oregon. *Vaccinium ovatum* is closely related to blueberries and cranberries as well as other huckleberry species. All of the native huckleberries and blueberries are important to wildlife. The success and timing of berry crops has been tied to the reproductive rate of

black bears, and berries are critical energy sources for neotropical birds at the time of migration. The plants themselves provide extensive cover for mammals and nesting birds as well as important winter browse. *Vaccinium* spp. are widely distributed throughout Europe, Asia, and North America; more than 40 species occur in North America.

Environmental and social benefits provided by U.K. woodlands/forests include open-access free recreation, landscape amenity, biodiversity and carbon sequestration (Woodhall and Sansford 2007, Sansford and others 2009). Studies to assign values to these benefits and timber values for Great Britain were reviewed by Sansford and Woodhall (2007). The estimated social and environmental benefits of British forests (based on estimated values of the recreational and biodiversity benefits, landscape value and carbon sequestration) are about £1022 million per year (2003 figures). Adding the estimated timber value of British forests (about £36 million), gives an estimated value of British forests of about £1058 million per year (2003 figures).

Costs: A major effect of *P. ramorum* in California coastal forests has been mortality of tanoak, coast live oak and California black oak (*Q. kelloggii*). Meentemeyer and others (2008) estimated 235,678 trees (12,650 m2 tree basal area) killed by *P. ramorum* in the Big Sur ecoregion (79,366 ha study area), of coastal California. The numbers represent about a 20 percent loss of available host trees. Non-lethal foliar and shoot infections occur on other susceptible forest species. The reduction of oak and tanoak populations in these forests has altered the forest stand structure and composition (Meentemeyer and others 2008). The USDA FS risk assessment (Kliejunas 2003) pointed out that heavy loss of oaks, or of related susceptible genera, due to *P. ramorum* infection could result in significant ecological effects, including changes in forest composition, loss of wildlife food and habitat, increased soil erosion and a significant increase in fuel loads in heavily populated urban-forest interfaces.

A pest risk assessment completed by the Plant Health Risk Assessment Unit of the Canadian Food Inspection Agency (CFIA) in March of 2002, and most recently revised in January, 2008 concluded that the potential environmental impacts of *P. ramorum* on most areas of Canada is low. For south coastal British Columbia, the risk is medium (CFIA 2008).

In Europe, any significant loss of oak species to *P. ramorum* could impact soil erosion, hydrology, biodiversity tourism and cultural history (Global Invasive Species Database 2006, Sansford and others 2009). Other hosts of *P. ramorum*—European beech (*Fagus sylvatica*) and sweet chestnut (*Castanea sativa*) for example—are important high forest and plantation trees in Europe (Global Invasive Species Database 2006).

Although the potential effects of *P. ramorum* on rare and endangered plant species are unknown, Cave and others (2007) list a number of genera on the APHIS List of Hosts and Associated Plants

(*Arctostaphylos confertiflora*, *A. glandulosa* ssp. *crassifolia*, *A. hookeri* var. *ravenii*, *A. morroensis*, *A. myrtifolia*, *A. pallida*, *Prunus geniculata*, *Q. hinckleyi* and *R. chapmanii*) that have species on the U.S. Fish and Wildlife Service Threatened and Endangered Species list (USFWS 2007).

Recreational Effects

Resources at Risk: Urban and woodland areas affected by *P. ramorum* in California have many federal, state, county and city operated parks and recreational facilities. Marin and Sonoma Counties are prime suburban and recreational areas. The economies of the Big Sur region and Santa Cruz are based largely on tourism and recreation.

Costs: Regulations and restrictions to prevent spread of *P. ramorum* affect recreational use of infested areas. Public access to areas may be restricted during certain seasons to prevent movement of the pathogen, or to protect visitors from hazardous trees killed by *P. ramorum*. The Rogue River – Siskiyou National Forest in Southern Oregon closed a popular trail just before Labor Day 2009 in response to detection of *P. ramorum* on a tanoak near the trail. Hazard tree removal from along trails in wilderness areas where chain saws are prohibited would need to be done with handsaws, thus increasing costs; this also increases the likelihood of trail closures due to a maintenance backlog in heavily impacted wilderness areas, such as the Ventana wilderness on the Los Padres National Forest. When visitors are requested or required to take precautions to prevent movement of the pathogen, park and forest staff may be required to provide educational information, staff cleaning areas, and provide appropriate supplies and equipment to remove soil from shoes and vehicles (COMTF 2004). Recreation may also be affected by a loss of recreational areas in woodland severely infested with *P. ramorum* (Appiah and others 2004).

Wildlife Effects

Resources at Risk: Tanoaks and true oaks provide habitat and food for a variety of wildlife (Standiford 2002). On the other hand, some small mammal species may benefit from loss of trees due to *P. ramorum*. In California, wood rats were projected to benefit from the increased shrub cover, California mice would benefit from an increase in coarse wood debris and brush mice would benefit from lower tree densities. Two salamander species modeled were likely to be relatively unaffected (Tempel and Tietje 2005).

Costs: Barrett and others (2006) indicated that the loss of *L. densiflorus*, *Q. kelloggii* and *Q. agrifolia* would have negative affects on dozens of wildlife species due to the direct loss of these three forest tree species, and the associated loss of food, nesting and den sites. Northern spotted

owls are known to nest in tanoak stands in coastal California and Oregon, and when combined with an overstory of large conifers, a component of tanoak may improve habitat for the owls by providing canopy structure and habitat for prey such as wood rats and northern flying squirrels (Niemiec and others 1995). A reduction of the oak overstory would also result in a more open canopy which would encourage dense shrub cover. In studies on the affect of the disease on insectivorous cavity-nesting birds in stands of coast live oak in the San Francisco area, Apigian and Allen-Diaz (2005) observed a loss of bird nest sites, prey reduction and loss of foraging substrates in P. ramorum affected plots. Monahan and Koenig (2006) reported a negative impact on populations of five California bird species associated with coast live oak in California. The authors projected that bird populations could be 25 to 68 percent smaller and 13 to 49 percent more variable in infested stands compared to non-infested stands. The greater number of beetles associated with infected trees (McPherson and others 2005) may also affect the feeding patterns of birds.

Fischer and Hadj-Chikh (undated) used regional risk models for *P. ramorum* to determine risk of habitat infestation to special status vertebrates in California, Oregon and Washington. In California, seven amphibians, five birds, seven mammals and one reptile had more than one third of their predicted habitat at risk of infestation. The numbers for Oregon were 15 amphibians, 18 birds, 21 mammals and two reptiles; and for Washington, 18 amphibians, 139 birds, 58 mammals, and 16 reptiles.

Program Costs

Government

United States Federal Agency expenditures on *P. ramorum* regulatory, research, management and related activities from 2000 to 2009 were: APHIS, $61 million; USDA FS, $39.9 million; Agricultural Research Service (ARS), $11.9 million; and Cooperative State Research, Education and Extension Service (CSREES), $1 million (Frankel, personal communication).

As stated previously, the U.K. Environment Minister will provide £25 million over five years (2009 through 2013) to help contain and eradicate *P. ramorum* and *P. kernoviae* in historic gardens, woodlands, heathlands and from nurseries and retailers in England and Wales.

Other

Other expenditures for *P. ramorum* include funds from the states of California, Oregon, and other states for education; state and federal salaries for researchers and forest health protection person-

nel; private grant and non-profit funds (for example, the Moore Foundation, Oregon Association of Nurseries, other nursery organizations, the Nature Conservancy); and others.

Summary

The current and estimated potential economic and environmental impacts of *P. ramorum* indicate a significant effect of the introduced pathogen. Current economic impacts to forests/woodlands have occurred primarily in central coastal California and southwestern Oregon. Economic losses there have been minor, as host mortality occurs primarily in non-timber species. Current economic impacts in the EU are estimated as minor to moderate. Potential economic losses have been estimated to be much greater if the pathogen becomes established in other areas, in particular the commercial forests of the northwest or eastern U.S. Economic impacts in urban areas include reduction in property value, and costs associated with hazard tree removal and fire management. Current economic impacts to the nursery/ornamental industry in the U.S. are estimated to be in the range of $100 to $300 million. Canada spent about $8.5 million in one year on control. Estimated future impacts if the pathogen spreads are much higher.

Environmental impacts from *P. ramorum* are not fully known because the introduced pathogen has been affecting forest ecosystems only since the mid-1990s and the nursery industry for less time. Estimates of potential environmental impacts vary widely (spanning several orders of magnitude), depending on assumptions made. The potential for *P. ramorum* to impact ecosystems depends on numerous factors, many of which are presently unknown.

Though the benefits and costs of various management scenarios have been estimated (see Hall and Albers 2009, and http://www.defra.gov.uk/corporate/consult/phytophthora-ram-kern/impact-assessment.pdf, for example), a comprehensive cost-benefit analysis of the disease has not been done.

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