Pacific Southwest Research Station

Sudden Oak Death

A 5-year Research Plan

Addressing the Emerging Threat

December 2002

USDA Forest Service, Pacific Southwest Research Station, Albany, CA

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Pacific Southwest Research Station

A 5-year Research Plan to Address the Emerging Threat Posed by Sudden Oak Death

Introduction. This document outlines a 5-year plan of research by the USDA Forest Service, Pacific Southwest Research Station (PSW) in response to Sudden Oak Death (SOD). We propose research that will: (a) produce a better understanding the pathogen and infection processes, (b) develop and evaluate diagnostic, management, and suppression practices, and (c) describe and evaluate ecological and socio-economic impacts. Early emphasis will be primarily on the pathogen, hosts, and site relations. Special attention will be given to coastal redwood, Douglas-fir, and other economically and ecologically important forest trees. Funding is proposed at $2.5 million per year for three years, then $2 million per year through year five.

Sudden Oak Death is a recently emerging disease of forest and urban trees, shrubs, and horticultural plants. It is presently known to occur in 12 coastal counties in California and one county in southwestern Oregon, and is known to infect 16 forest trees and shrubs and numerous ornamental *Rhododendron* species. Recently announced hosts include California's coastal redwood (*Sequoia sempervirens*), and Douglas-fir (*Pseudotsuga menziesii var. menziesii)* and big-leaf maple (*Acer macrophyllum)* in the Sierra Nevada. Laboratory studies have demonstrated susceptibility of pin oak (*Quercus palustris*) and northern red oak (*Q. rubra*), two important stalwarts of our eastern deciduous forests. These announcements, coupled with observation of *P. ramorum* disease on many additional plant species in botanical gardens at the University of California, Berkeley, raise concern to an even higher level.

The disease was first observed in 1995 as large numbers of tanoaks *(Lithocarpus densiflorus)* were reported dying in Marin County California. By July 2000, plant pathologists reported that the trees were killed by a previously undescribed forest pathogen—*Phytophthora ramorum*. Trees appeared to die quickly as the disease spread across the region, thus the new disease was named Sudden Oak Death. SOD continues to expand since these initial observations and has killed hundreds of thousands of trees. Using the evaluation process established by the North American Forestry Commission, the Forest Service has rated Sudden Oak Death as a high-risk disease.

We have learned much over the past 36 months about *P. ramorum*, and how this emerging disease threatens our forest and urban landscapes, our agricultural, horticultural, and nursery practices, and associated markets and economies. There remains much that we do not know. Response to SOD has been an outstanding example of coordination and partnership as management and regulatory actions were described, deployed, and modified as our scientific knowledge developed and grew.

The PSW Research Station has been an important contributor of scientific leadership, research coordination, and financial support for the science needs of Sudden Oak Death. Studies funded by the USDA Forest Service and conducted by research scientists at the Davis and Berkeley campuses of the University of California were first to identify *P.*

ramorum as the primary cause of Sudden Oak Death. Additional scientists were engaged, and have responded to quickly produce a basic core of understanding that was necessary for early management and regulatory response. We now need to move forward to expand our understanding, to validate these actions, and/or create new, longer-term management practices and regulatory policy. We also need to build on the information and experiences of others. Sudden Oak Death also appears to be an emerging problem in Europe, especially in the nursery industry. The PSW Research Station recently entered into research agreement with leading European *Phytophthora* scientists to consider relationships of the U.S. pathogen to known presence in England, The Netherlands, and Germany.

Background. Hundreds of thousands of tanoak, coast live oak (*Q. agrifolia*), and black oak (*Q. kelloggii*) have died from infection by *P. ramorum* since SOD was first observed in 1995. Many more are infected. The host range of *P. ramorum* continues to expand. Recent announcement of Douglas-fir and coast redwood increases the number of recognized host-species in California and Oregon to 16. The occurrence of the disease in common nursery plants, such as rhododendron, raises significant concern regarding the sale and movement of such plants--which may provide a critical avenue for disease spread into currently unaffected areas, such as the recent occurrence of the disease in southern Oregon some 250 miles north of the northernmost known occurrence in California.

Tree, shrub, and horticultural-plant hosts may exhibit a variety of symptoms, but hosts have been broadly categorized as: **bark-canker hosts** and **foliar hosts (**Figure 1). Bark-canker hosts include tanoak and four oak *(Quercus)* species. Infected trees typically display crown dieback or wilting, stem/bark lesions, basal cankers, and reddish to dark brown exudations typical of infections caused by other species of *Phytophthora.* Death can occur within 1 – 2 years. Often, as trees die, leaves change from green to brown within a period of weeks--thus the name Sudden Oak Death. Foliar hosts include a variety of tree, shrub, and horticultural plants on which symptoms are seen primarily on leaves and small stems. These hosts are infected but not necessarily killed, and may be a primary source of inoculum for further spread.

Figure 1. Currently recognized *P. ramorum* host list:

Bark Canker Hosts: Bark canker hosts include tanoaks and oaks that become infected on the tree trunk; hosts exhibiting these characteristics frequently die. The earliest symptom is appearance of a bleeding canker. Burgundy-red to tar-black thick sap oozes on the bark surface. Tanoaks belong to both categories, developing bark cankers as well as foliar and twig infections.	
Common Name:	**Latin Name:**
Tanoak	*Lithocarpus densiflorus*
Coast live oak	*Quercus agrifolia*
California black oak	*Quercus kellogii*
Shreve's oak	*Quercus parvula var. shrevei*

Foliar Hosts: These hosts become infected, but are not necessarily killed. Symptoms are seen primarily on the leaves and small twigs. Researchers have observed that, in some host species, the pathogen can reproduce on the leaf surface, providing rapid build-up of spores, and therefore serving as a significant source of inoculum and infection.	
Common Name:	**Latin Name:**
Big leaf maple	*Acer macrophyllum*
Madrone	*Arbutus menziesii*
Manzanita	*Arctostaphylos* spp.
California buckeye	*Aesculus californica*
California coffeeberry	*Rhamnus californica*
Douglas-fir	*Pseudotsuga menziesii var. menziesii*
Coast redwood	*Sequoia sempervirens*
California bay laurel	*Umbellularia californica*
Rhododendron	*Rhododendron* spp.
Evergreen huckleberry	*Vaccinium ovatum*
Honeysuckle	*Lonicera hispidula*
Toyon	*Heteromeles arbutifolia*
Arrow wood (Germany, United Kingdom, Netherlands)	*Viburnum* spp.

(Source: www.suddenoakdeath.org)

Although mechanisms for spread and dispersal are not fully understood, *P. ramorum* is likely to spread by deciduous sporangia that are produced on foliar hosts, then carried in rainwater, streamwater, and soil. *Phytophthora* species also produce thick-walled chlamydospores. These dormant spores may provide the organism with an ability to survive adverse conditions for long periods of time in soil, wood or other host tissues. Anthropomorphic movement of infested plant material, water, or soil may be a major pathway for long-distance transport of the pathogen.

Approximately 60 species of *Phytophthora* are known worldwide, many of which have caused serious epidemics in agricultural crops (e.g. the infamous Irish potato famine in the 1840s) and forests (e.g. *Eucalyptus* in Australia, Port-Orford cedar in Oregon). We do not know whether *P. ramorum* is a recently introduced pathogen, a suddenly emerging native organism, or a recent hybrid between other species of *Phytophthora*. *P. ramorum* also occurs in Europe on rhododendron and viburnum, and is emerging as a critical international trade issue. Thus far, it appears that the American and European populations are genetically distinct, suggesting that Europe was probably not the source for the American population. The American and European populations each appear to have one of the two mating types necessary for sexual reproduction. Should these two mating types come in contact, recombination due to sexual reproduction could further increase virulence or the host range of *P. ramorum*.

Expansion of SOD within its current geographic range, and frequent confirmation of new hosts, has raised or increased concerns nationwide. Generalized national projections of risk

have been generated based on tree species distributions and current understanding of important environmental and site factors (**Figure 2**).

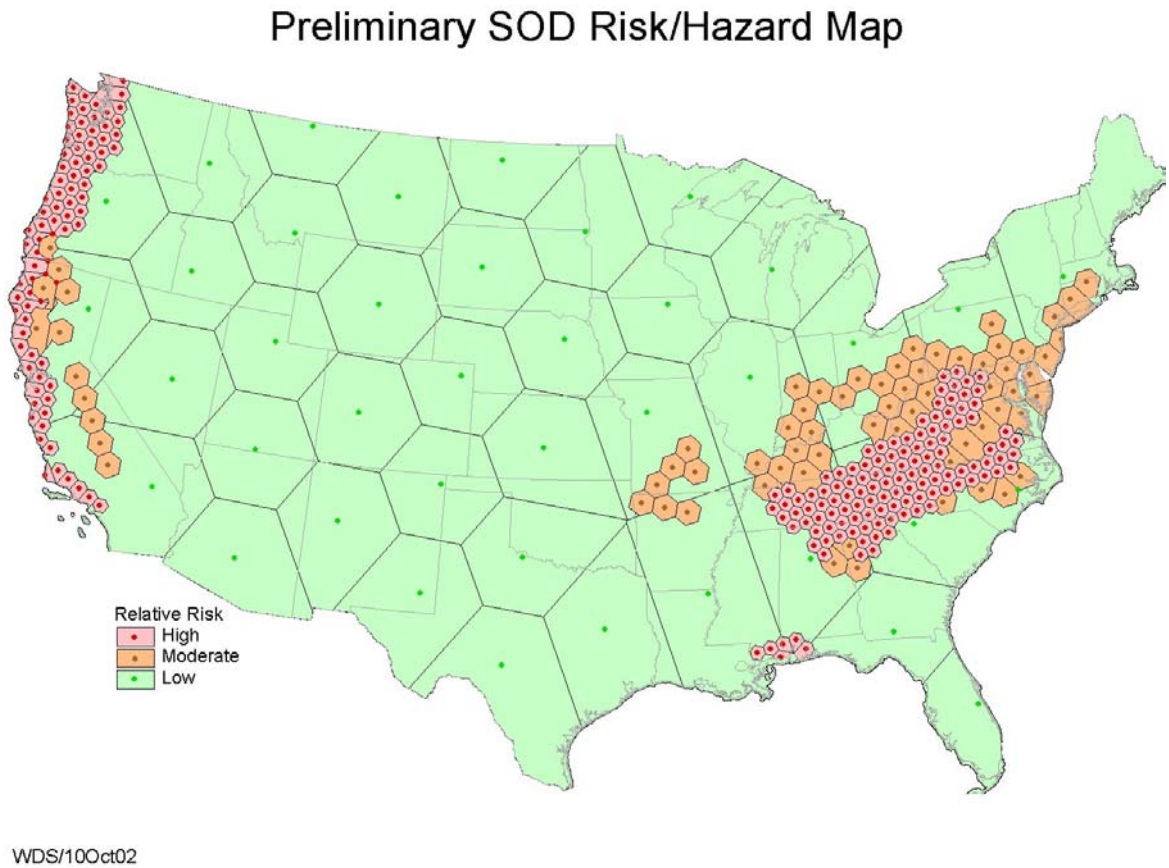

Figure 2. National Sudden Oak Death Preliminary Risk Map—based primarily on forest type and local environmental conditions. (Polygon size relates to base-data density and does not indicate risk)

Research and Funding History. No permanent Forest Service Research and Development funds have been appropriated for SOD. However, the Pacific Southwest Research Station administered $3.480 million in 2001 and 2002 to support research addressing critical information needs. No funds for SOD research are included in the PSW Research Station's budget for 2003.

Funding for research support in FY 2001-2002 was secured from a variety of sources. A total of $3 million Federal funds came from the USDA Forest Service, the Commodity Credit Corporation (through an emergency authorization), and a 2001 Congressional supplemental appropriation. The California Department of Forestry and Fire Protection contributed $480,000. An additional $200,000 was redirected within the PSW Research Station in 2002 to support research and administrative functions. PSW SOD Program managers worked with research and management representatives of the California Oak Mortality Task Force to select 22 projects involving 12 university and institutional partners. These projects have produced most of the basic information necessary for scientific

underpinnings of SOD management action and regulatory policy (a list of studies and institutional partners is included in **Appendix I**).

Uncertain and inconsistent year-to-year funding has restricted the rebuilding of scientific capacity in plant pathology at the PSW Research Station. Without consistency, research planners cannot develop thoughtful, reasoned, and structured plans that maintain staffing to address future invasive threats. With SOD, we were fortunate to have university cooperators available with appropriate skills. Future funding for their research is also uncertain, and university capacity is strained. Reestablishment of long-term capacity is critical for the Forest Service and universities to respond to current and future invasive-organism introductions.

The Pacific Southwest Research Station should remain the central focus for planning and coordinating of SOD research. *P. ramorum* is known to occur only in California and southwestern Oregon in the U.S. Quarantine regulations and common sense prevent transporting study specimens to other regions of the country. The San Francisco Bay Area has been the center of *P. ramorum* activity, with 6 of the 12 infested counties. Consequently, it also offers a core of scientific expertise on *P. ramorum*, with contacts and collaboration extending around the nation and the globe. The 75 agency-members of the California Oak Mortality Task Force have demonstrated outstanding performance in planning and coordinating the SOD response. The PSW Station is a member of this task force and is well positioned to continue our role in science coordination and research leadership. This plan outlines priority research that builds on our existing knowledge and partnerships to expand scientific understanding in the currently affected area, as well as to address the disease as it expands to new hosts and new geographic regions.

Five Year Research Plan. The PSW 5-year SOD plan proposes research in four areas. These are:

I. **Pathogen Biology, Hosts, and Epidemiology.**
II. **Disease Management and Resource Utilization.**
III. **Disease Impacts on Ecosystem Components.**
IV. **Economic and Social Impacts.**

Emphasis in the early stages of this research will continue on the pathogen and developing a critical core of understanding—[e.g. What is the full range of potential hosts? How does the disease disperse? What are effective treatment strategies? What are the short-term and long-term ecological effects? What are the epidemiological parameters that will allow us to forecast and predict disease spread? What is the effect of *P. ramorum* disease on crucial economic hosts like redwood and Douglas-fir?] Domestic quarantine regulations have been developed and released by the USDA Animal and Plant Health Inspection Service and California Department of Food and Agriculture. Answers to the above questions are critically needed to support in-place and new regulatory and management actions.

As we gain further knowledge, we can be more creative in designing and implementing new management and control strategies. We will consider additional management tools, examine their effectiveness, and expand on methods to safely dispose of, or utilize, affected material.

In addition, we will be more certain of the need for, and effectiveness of, our regulatory policies.

Broader and deeper ecological questions should also be addressed regarding the impacts to ecosystems in which the pathogen occurs, as well as far-reaching social and economic implications. Tracking of international efforts and close collaboration with international investigators and managers are essential to questions of international trade.

The elements of this research plan are summarized below and in greater detail in **Appendix II**.

I. Pathogen Biology, Hosts, and Epidemiology. Research will focus on augmenting and accelerating ongoing investigations on the origin and nature of this new species of *Phytophthora*. These studies are critical to understanding the disease and in designing control or management strategies. Investigations will focus on gaining a better understanding of the genetic structure and geographic origins of the pathogen, its cultural characteristics, growth habits and attributes, and mechanisms of survival, spread, and intensification. Initial studies will look at disease diagnosis and detection, mechanisms of infection, disease development and individual host responses, susceptibility of host species within and beyond California and Oregon, tree-to-tree spread and intensification, and evaluation of associated conditions and organisms (including possible vectors).

II. Disease Management and Resource Utilization. Investigations will continue on disease treatment and control methods, including the effectiveness of various quarantine and containment actions, chemical applications, breeding for disease resistance, and how to dispose of or utilize trees killed by the pathogen. This effort is essential to help ensure the long-term health of currently unaffected areas and the restoration of areas that have been impacted.

III. Disease Impacts on Ecosystem Components. Priority will be given to understanding *P. ramorum* disease and potential impacts on Douglas-fir and coastal redwood. Investigations will also focus on the various direct and cascading effects of this unprecedented level of oak mortality on ecosystem structure and function. Examples of investigations in this area include clarification of interrelationships of host plants affected and on the effects of mortality on: fire hazard and risk, especially in the wildland/urban interface; forest and site productivity; biodiversity; wildlife habitat; water regimes; hill slope stability; susceptibility to invasion by exotic plants, and similar impacts within and beyond California and Oregon. PSW scientists and managers will involve and interact with university cooperators and other partners on all aspects of these investigations. Results of these studies are critical to development of management actions and strategies to prevent and minimize impacts, particularly the immediate increases in fire risk caused by Sudden Oak Death that threaten recreation, ranching/grazing operations, timberlands, and commercial timber production.

IV. Economic and Social Impacts. Sudden Oak Death potentially can have a tremendous direct impact on forest, agricultural, urban, and horticultural economies in affected areas. Direct costs associated with management and quarantine efforts are substantial. These direct

impacts, however, are likely overshadowed by the indirect economic impacts of intrastate, interstate, and international quarantine regulation of agricultural, horticultural, and forest commodities. These impacts will be investigated, along with other social and economic considerations that may affect costs, property, and other values of individual homeowners and landowners, including costs and revenue loss by counties, communities, and individuals.

Budget. Continued and consistent funding at $2.5 million per year is required for the first three years, and $2.0 million per year for years four and five. A breakdown by year and research element is presented in **Figure 3.** The Areas of Emphasis described in this plan represent only general direction and priority at this stage. Specific studies and fund distributions must evolve as we learn, and as our knowledge and priorities further develop.

At present no funds are available to implement this plan. The critical element of our research now is time. The pathogen has been identified and investigations have been initiated. Time and focused research are now essential to further clarify early observations, and to understand the disease as it expresses itself through early stages of development and expansion.

Staffing and Organization. The Sudden Oak Death Research Program at the PSW Research Station will continue as a blend of internal and external cooperative research involving a variety of external partners. Collaborative projects will be selected through a competitive process, open to all scientists, based on priorities and selections guided by knowledgeable members of the scientific, management, and regulatory communities.

Primary responsibility for program oversight will be assigned to one of the Station's Assistant Directors for Research. A designated SOD Project Manager will be responsible for day-to-day management.

If longer-term funds become available, one or more research plant pathologists will be recruited to begin restoration of research capacity at PSW to address SOD--and other potential future invasive pathogens. Care will be taken in selecting candidates and assigning research responsibility, to minimize overlap with other research programs, and to focus on high-priority knowledge gaps that are not addressed by other organizations and researchers.

Figure 3. BUDGET. PSW Research Station 5-year Sudden Oak Death Research Plan—Proposed funding by year and research area.

Research Elements and Areas of Emphasis	Funding Per Year ($ Thousands)				
	2003	**2004**	**2005**	**2006**	**2007**
Pathogen Biology, Hosts, and Epidemiology	900	900	800	500	500
Pathogen characteristics and mechanisms of infection					
Characteristics of host and site susceptibility, and methods to assess risk to infection, especially redwood and Douglas-fir					
Rapid and more accurate methods to detect and evaluate *P. ramorum* and associated organisms in host plants					
Mechanisms of short and long-range spread					
Role of associated organisms (fungi, insects, wildlife, humans, etc) in the disease process					
Disease Management and Resource Utilization	700	700	700	500	500
Methods to effectively and safely dispose of infected material					
Individual tree treatments, and interface with arboricultural practices					
Stand and landscape treatments					
Improved monitoring practices, including survey and remote sensing tools					
Methods to evaluate potential, and project tree failure					
Disease Impacts on Ecosystem Components	800	800	800	800	800
Assess impacts of tree mortality and changing vegetation structure on ecosystem communities, including elevated ecological threats from factors such as wildfire, flooding, landslides, exotic plant invasions, etc.					
Economic and Social Impacts	100	100	200	200	200
Economic impacts of SOD to trade and movement of forest and agricultural products; special emphasis will be given redwood and Douglas-fir					
Economic and social impacts to values of individual homeowners and landowners and to communities					
ANNUAL TOTALS	2,500	2,500	2,500	2,000	2,000

APPENDICES:

Appendix I. Summary of Sudden Oak Death Research Projects Funded by the Pacific Southwest Research Station. May 2001 – December 2002

Appendix II. Research Elements and Priority Rankings for Sudden Oak Death Research Under the PSW Research Station 5-year Research Plan

Appendix I

Pacific Southwest Research Station

Sudden Oak Death

December 2002

Introduction

Sudden Oak Death is a growing threat to California and to forest trees, horticultural and agricultural plants, and the economy here and elsewhere. This emerging new disease, caused by the pathogen *Phytophthora ramorum,* is the subject of vigorous scientific investigation. In 2001-2002, the Pacific Southwest Research Station (PSW), USDA Forest Service, Albany, CA, secured and administered $3.48 million for scientific investigation of Sudden Oak Death disease. Funds supported 22 projects with 12 university or other research partners addressing critical information needs. Projects were prioritized and selected to develop basic information on this new disease necessary to provide the scientific underpinnings for management and regulatory actions. Research projects addressed information needs in four areas:

- Pathogen Biology, Hosts, and Epidemiology
- Disease Management and Resource Utilization
- Disease Impacts on Ecosystem Components
- Economic and Social Impacts

Background and Funding

No additional research funds are budgeted for Sudden Oak Death at the PSW Research Station for 2003. While no *permanent* Forest Service Research and Development funds have been available, funds for 2001-2002 were secured from a variety of sources. Three million dollars came from USDA Forest Service, the Commodity Credit Corporation (an emergency authorization), and the U.S. Congress (2001 supplemental appropriation). The remaining $480,000 came from the California Department of Forestry and Fire Protection.
The PSW Research Station Sudden Oak Death Research Program has been instrumental in planning, managing, coordinating, and funding research to meet the information needs of Sudden Oak Death. We look forward to continued partnerships in the future.

For projects supported by these funds, see the following pages.

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Pacific Southwest Research Station

FY 2001 - 2002 Funded Projects

University of California, Berkeley, CA

Project Title **Determination of population structure, phylogenetic placement, species state of *Phytophthora ramorum,* and development of a quick and accurate diagnostic methodology**
Objectives (1) Determine the phylogenetic placement and evolutionary history of this new *Phytophthora*. (2) Develop methodologies for quick and accurate diagnosis of the new *Phytophthora*.
Funding $446,770, for 3 years, from PSW Research Station
Dr. Matteo Garbelloto, Forest Plant Pathologist

Project Title **Studies on treatment for prevention, management, and sanitation of Sudden Oak Death disease, with a particular emphasis on chemical treatments and composting**
Objectives (1) Test various preventative treatments for protection from infection by Sudden Oak Death. (2) Test various treatments to retard the progression of Sudden Oak Death. (3) Test the efficacy of composting and heat treatments to reduce or eliminate pathogen viability.
Funding $152,000, for 2 years, from PSW Research Station and California Department of Forestry and Fire Protection
Dr. Matteo Garbelloto, Forest Plant Pathologist

Project Title **Detection and identification of decay and pathogen fungi directly from wood: A novel approach for the assessment of decay and disease in trees affected by Sudden Oak Death**
Objective Develop a method to detect and identify the presence of associated decay organisms at all stages, from incipient to advanced, in urban and landscape trees infected with Sudden Oak Death disease.
Funding $40,107, for 1 year, from PSW Research Station and California Department of Forestry and Fire Protection
Dr. Matteo Garbelloto, Forest Plant Pathologist

Project Title **Identifying Sudden Oak Death resistant genotypes to susceptible species in coastal oak woodlands**
Objectives (1) Assess genetic architecture of tanoak, coast live oak, California black oak and Shreve oak using AFLP [Amplified Fragment Length Polymorphism] molecular markers. (2) Look for correlated genetic markers and disease resistance in the four species. (3) Develop rapid methods of genetic fingerprinting for identifying resistant genotypes. (4) Determine whether populations with low genetic diversity are at higher risk of loss from disease. (5) Predict the risk of disease in populations not yet infected.
Funding $135,922, for 2 years, from PSW Research Station
Dr. Richard Dodd, Professor of Forestry, Department of Forest Science

Project Title **Continuation of intensive research plot monitoring across the range of Sudden Oak Death**
Objectives (1) Detect newly infected trees in plots where year-2000 baseline conditions are known. (2) Place intensive monitoring plots in areas of infected forests in both the northern and southern limits. (3) Determine the sequence of symptom appearance for each tree species and the time from initial seeping-canker observation to the development of

additional symptoms such as bark-beetle attack, appearance of fruiting bodies of *Hypoxylon thouarsianum*, or foliage death. (4) Follow the physical breakdown of infected trees after death. (5) Correlate the infection status of trees determined through ground-level inspection with remote-sensed multi-spectral reflectance. (6) Develop predictive models for tree infection and mortality as a function of tree populations.
Funding $51,542, for 1 year, from PSW Research Station

Dr. Richard Standiford and **Dr. N. Maggi Kelly**, College of Natural Resources

Project Title **Interactions of bark and ambrosia beetles with *Phytophthora ramorum* in coast live oaks and their role in tree failure**
Objective (1) Determine the role(s) played by bark and ambrosia beetles in decline, death, and failure of coast live oaks infected with *P. ramorum*.
Funding $75,000, for 2 years, from PSW Research Station and California Department of Forestry and Fire Protection

Drs. Richard Standiford, David Wood, Andrew Storer, Pavel Svihra, and Tjosvold

Project Title **Ecological impacts of Sudden Oak Death on coast live oak and tanoak/redwood ecosystems**
Objectives (1) Compare and contrast stand structure, species composition and environmental characteristics in coast live oak woodlands in infected and non-infected stands in Marin, Napa, Alameda, and Contra Costa counties; (2) Use historic Vegetation Type map data to locate additional plots to examine historic vegetation change in coast live oak communities; (3) Determine the relationship of spatial patterns of individual stems to patterns of disease spread. (4) Reconstruct height and diameter development of stands under various levels of infections. (5) Establish thinning and burning plots to assess the effect of alterations in stand structure on disease spread. (6) Determine if the composition and relative abundance of birds, mammals, and herpetofauna is affected by SOD and associated stand structure. (7) Determine the effects of an change in stand structure on the abundance, species composition, productivity, roosting, and foraging of secondary cavity nesting birds and predators of these birds. (8) Compare the diets of insectivorous birds in infected and non-infected areas. (9a) Determine how insect species of particular importance to the diet of secondary cavity-nesting birds respond in areas affected by SOD. (9b) Provide plant pathology capabilities for multiple Principle Investigators (an addendum to 9a, funded separately from 1-9a with $35,000 jointly by PSW and CDF&FP.
Funding $534,734, for 3 years, from PSW Research Station and California Department of Forestry and Fire Protection)
Drs. Barbara Allen-Diaz, Donald Dahlsten, Kevin O'Hara, Scott Stephens, William Tietje
College of Natural Resources, Departments of Forest Science, Environmental Science, Policy and Management

University of California, Davis, CA

Project Title **Studies to determine mechanisms of survival, spread, population structure, and other biological characteristics of *Phytophthora ramorum***
Objectives (1) Determine the mechanisms of survival, spread, and intensification of SOD. (2) Determine the population structure, mating genetics, and species status of the new *Phytophthor*a. (3) Determine the susceptibility of host species within and beyond California.
Funding $398,770, for 3 years, from PSW Research Station
Dr. David Rizzo, Associate Professor Plant Pathology

Project Title **Epidemiology, biology, and impact of *Phytophthora ramorum* in the Sierra Nevada**
Objectives (1) Determine the mechanisms of survival, spread, and intensification of *Phytophthora ramorum* in the Sierra Nevada mountains. (2) Determine the potential effects of the pathogen in those areas where the pathogen appears to be established
.

Funding $210,000, for 3 years, from PSW Research Station and California Department of Forestry and Fire Protection

Dr. David Rizzo, Associate Professor Plant Pathology

Project Title **Disease progression and sporulation potential of *Phytophthora ramorum* on non-oak hosts**
Objectives (1) Document symptoms and disease progression on all identified non-oak hosts of *P. ramorum*. (2) Determine the sporulation potential of the pathogen on these hosts. (3) Determine host range and symptom development of *P.* "ilicis-like" on non-oak species.
Funding $210,000, for 3 years, from PSW Research Station and California Department of Forestry and Fire Protection

Dr. David Rizzo, Associate Professor Plant Pathology

University of California, Forest Products Laboratory, Richmond, CA

Project Title **Utilization and disposal of *Phytophthora ramorum* infected oak and coordination of the PSW Sudden Oak Death research program: An effort to retard the spread of Sudden Oak Death syndrome in the coastal habitat of California**
Objectives (1) Analyze the technical feasibility of using *Phytophthora*-infected material for wood products, including composites, solid wood, and fuel and firewood (chips, firewood, and densified fuel). (2) Assess the risk of pathogen survival in processed products. (3) Test control methods for wood products including heat, chemical, and other typical wood pathogen control methods such as heat sterilization, and the effect of temperature and its correlation with wood thickness and moisture content and the effectiveness of sodium borates.

Also, the Forest Products Laboratory will provide PSW with a SOD Research Program Coordinator whose responsibilities include (1) development of a program of research through partnerships with academia as well as the State and other public and private entities; (2) recruitment and negotiation of research agreements; (3) tracking progress of PSW funded research; (4) representing PSW at all appropriate local, regional, national, and international meetings concerning SOD; (5) providing assistance to the PSW management team to effectively utilize appropriated funds; (6) ensuring Forest Service recognition of research efforts; and (7) initiating and organizing meetings of research cooperators to coordinate research and utilization of research sites.
Funding $216,000, for 3 years, from PSW Research Station

Dr. Frank Beall, Director

University of California Cooperative Extension, Watsonville, CA

Project Title **Evaluation of fungicides for the control of *Phytophthora ramorum* infecting containerized plants**
Objective Determine the efficacy (including residual properties) of fungicides that could be used by nurserymen to prevent infection by *Phytophthora ramorum* of containerized *Rhododendron* spp.
Funding $18,000, for 1 year, from PSW Research Station

Dr. Steve Tjosvold

California State University-San Luis Obispo, CA

Project Title **The effect of Sudden Oak Death on mortality, long term growth, and economic viability of coast live oak in three California counties**
Objectives (1) Collect and analyze volume, growth, yield, and economic data from thinned and unthinned, permanent, oak-dominated plots established in 1984 in Monterey, San Luis Obispo, and Santa Clara counties (all counties with positive ID of SOD). (2) Starting this

year these plots will also be assessed for the presence, incidence, and effect of SOD on thinned and unthinned plots throughout the study areas.
Funding $52,000, for 3 years, from PSW Research Station
Dr. Norman Pillsbury, Natural Resources Management Department

Lewis and Clark College, Portland, OR

Project ***Title*** **A cytological and histological study of *Lithocarpus* and *Quercus* spp. infected with *Phytophthora ramorum***
Objectives (1) Study the infection process of *P. ramorum* in *Lithocapus densiforus* and *Quercus* spp. (2) Gather cytological and histological data to facilitate discovering the portal of entry into the host and the sequence of tissue infection. Addendum to above project: provide laboratory assistance with sample preparation for electron microscopy.
Funding $20,000, for 1 year, from PSW Research Station
Dr. Edwin R. Florance, Professor of Biology

Oregon State University, Corvallis, OR

Project Title **Epidemiology of *Phytophthora ramorum* in Oregon forests**
Objectives (1) Determine mating types and other measures of population structure of American and European isolates of *P. ramorum*. Also, with California colleagues, test hypothesis of origin of the pathogen, including (a) *P. ramorum* in Oregon is a recent introduction from California and (b) *P. ramorum* in California is a recent introduction from Europe. (2) Examine the mechanisms by which the pathogen infects, survives, and is dispersed under Oregon conditions, with emphasis on (a) susceptibility of common wild and cultivated *Ericaceous* shrubs, (b) epidemiology on susceptible plants growing beyond the range of susceptible tree species, and (c) the importance of soil- and water-born inoculum in disease development and spread.
Funding $218,009, for 2 years, from PSW Research Station
Dr. Everett Hansen, Department of Botany and Plant Pathology

Phytosphere Research, Vacaville, CA

Project Title **Evaluation of water stress and other risk factors for *Phytophthora ramorum* canker in coast live oak and tanoak**
Objectives (1) Remeasure stem-water potentials of symptomatic and non-symptomatic coast live oak and tanoak to document any changes in water stress over this period and assess the relationship between water stress and disease progress. (2) Reassess disease occurrence and severity of coast live oak and tanoak subject trees and plot trees 1 year after initial evaluations to document disease progression. (3) Collect data on additional selected plot and tree variables that may be related to disease. (4) Refine statistical models that relate disease risk with water stress and plot variables, and develop disease progress models.
Funding $33,924, for 1 year, from PSW Research Station
Dr. Tedmud J. Swiecki

Project Title ***Phytophthora ramorum*** **(Sudden Oak Death) in coast live oak and tanoak: Factors affecting disease risk, disease progression, and failure potential**
Objectives (1) Develop and refine statistical models that relate disease risk, disease progress, and mortality with tree factors and plot variables. (2) Assess how failure potential relates to SOD disease progress and mortality by observing tree failures over time and determining which factors observed prior to failure are most predictive of failure; (3) Document disease progress and new infections occurring within plots to provide information on disease phenology and initiation: (3) Determine how tree water status is affected by disease over

time by documenting changes in water stress that develop as SOD symptoms progress.
Funding $50,415, for 1 year; from PSW Research Station and California Department of Forestry and Fire Protection

Dr. Tedmud J. Swiecki

Project Title **Relationship between tree failure potential and *Phytophthora ramorum* canker (Sudden Oak Death)**
Objectives (1) Conduct field surveys to determine whether certain observable tree and stand factors are related to failure risk; (2) Statistically assess the relative importance of various agents and factors in predisposing trees to failure; (3) Compare field survey findings with data from the California Tree Failure Reporting Program database to determine whether differences exist in failure patterns in urban and wildland oaks; (4) Develop a protocol for assessment of failure potential in coast live oak affected by SOD based on previous findings.
Funding $50,000, for 1 year, from PSW Research Station and California Department of Forestry and Fire Protection

Dr. Tedmud J. Swiecki

Pacific Southwest Research Station with Humboldt State University, Arcata, CA

Project Title **Field evaluation to study a method of potential transmission of Sudden Oak Death (*Phytophthora ramorum*) by birds**
Objectives (1) Establish a method of surveying for the presence of the pathogen on birds. (2) Determine the likely species involved, timing, and incidence rate of the pathogen.
Funding $74,000, for 2 years, from PSW Research Station

Dr. C.J. Ralph, Redwood Sciences Laboratory, Arcata
Dr. Erick S. Jules, Humboldt State University

Pacific Southwest Research Station, Davis, CA

Position: **Post-Doctoral Plant Pathologist**
The SOD program will provide operating funds for this position, starting with $70,000; salary and overhead support will come from PSW research appropriations. The incumbent's primary research responsibility is to develop the necessary protocols for testing laboratory susceptibility and field infection rates of SOD on various species of oaks, both those native to California and those found elsewhere in the United States. The incumbent will be given a term appointment and housed in the laboratory of Dr. Rizzo, University of California, Davis because the lab has the necessary equipment and Dr. Rizzo the expertise to guide this research.
Funding $70,000, for 1 year, from PSW Research Station

Wildlife Conservation Society, Santa Cruz, CA

Project Title ***A study to determine the role of vertebrate vectors (birds and small mammals) in spreading Phytophthora ramorum***
Objectives (1) Determine whether wildlife can act as vectors of *P. ramorum*. (2) Determine taxa with potential to play a significant role in dispersal of inoculum. (3) Identify the means by which viable inoculum can be transported. (4) Map the potential inoculum shadows produced by potential vectors. (5) Develop management recommendations to reduce *P. ramorum* dispersal.
Funding $45,000, for 1 year, from PSW Research Station and California Department of Forestry and Fire Protection

Drs. Keyt Fischer, **Steve Zack**,
Cheryl Blomquist, California Department of Food and Agriculture; **Eric Sanderson**

International Research

Project title **Comparative aggressiveness of European and U.S. isolates of *Phytophthora ramorum* on *Quercus rubra***
Objectives (1) Determine the aggressiveness of European and USA isolates of SOD to infect red oak. (2) Determine the susceptibility of European and USA isolates of SOD to antifungal agents. (3) Determine the genetic differences of European and USA isolates of SOD.
Funding $45,468

Dr. Clive Brasier, Pathology Branch, Forest Research Agency;
Alice Holt Lodge, Dr. Sabine Werres, Phytopathologist and Mycologist, Federal Biological Research Center for Agriculture and Forestry, Braunschweig, Germany;
Dr. Willem A. Man, Dr.. R. P. Baayen, Dutch Plant Protection Service, Wageningen, Netherlands

Appendix II. Research Elements and Priority Rankings for Sudden Oak Death Research Under the PSW Research Station 5-year Research Plan \1

Research Elements and Areas of Emphasis	**Priority**
I. PATHOGEN BIOLOGY, HOSTS, AND EPIDEMIOLOGY	
A. Pathogen characteristics and mechanisms of infection	
Role of soil-borne *P. ramorum* in infection. Determine whether sporangia/chlamydospores can be moved in soil and infect hosts—are there differences in infectivity due to wet and dry seasons or types of conveyances (automobiles, bikes, logging equipment, horses)	HIGH
Levels of associated microbial antagonism and role in infection process	HIGH
Importance and role of sporulation from non-oak hosts on infection process	HIGH
Describe mechanism of spread from initial host inoculation of host, spread within host, and to others	HIGH
Develop a model of distance sporangia/chlamydospores can travel in various air-flow regimes. Identify the distance/size relationship of various resting forms of *P. ramorum* and how they affect dispersion.	HIGH
Assess survivability of spores/chlamydospores over time in various substrates (soil, bark, xylem tissue, leaves)	MOD
B. Characteristics of host and site susceptibility and methods to assess risk to infection	
Expand studies of host susceptibility in other geographic areas on the West Coast (outside the San Francisco Bay Area), especially the California north coast, southwestern Oregon, and the Sierra Nevada	HIGH
Develop host index/geographic extent for all hosts. Assess symptoms and disease progression on all hosts. What do symptoms reveal about sporulation?	HIGH
Characteristics of tree susceptibility to canker infection i.e vigor, growth rate, genetic architecture, population structure, size/age class	HIGH
Role of genetics and species composition in infection risk/resistance	HIGH
Develop information on climatic limits (temperature, moisture, humidity, precipitation) of *P. ramorum*; apply to risk models	HIGH
Describe environmental factors, stand structure, species composition, and site characteristics that favor spread?	HIGH
Disease progression and effect of *P. ramorum* on growth, survival, and seed production on major economic hosts like Douglas-fir and coastal redwood	HIGH
C. Methods to more easily and accurately detect and evaluate *P.ramorum* and associated organisms in host plants	
Develop more efficient DNA extraction methods	HIGH
Develop procedures to handle large numbers of samples. (How much can samples be pooled before losing sensitivity?)	HIGH
Design new, rapid, and simple testing tools to assess presence of *P. ramorum* in field	HIGH

Develop diagnostic practices for horticultural industry. Is *P. ramorum* present in soil of potted plants? If infected plant parts are pruned, is P. ramorum still present in asymptomatic plant parts?	HIGH
D. Identify mechanisms of short- and long-distance spread	
What are the possible vectors for spread? Assess air/wind, insects, birds, humans, commerce/products, soil movement, logs	HIGH
Examine the potential role of fire in moving spores (wildfire, prescribed fire, burn piles)	MOD
E. Role of associated organisms (fungi, insects, wildlife, humans, etc) in infection and disease process	
Interaction between other mortality factors and *P. ramorum*. (*Armillaria*, other *Phytophthora*, canker rots, *Diplodia*, *Verticillium* wilt)	MOD
Role of insects in mortality. (How long does it take for a tree to die, with and without other organisms present?)	LOW
II. DISEASE MANAGEMENT AND RESOURCE UTILIZATION	
A. Methods to effectively and safely dispose of infected material	
Shape, size, duration of composting on *P. ramorum* viability. Scale up from small-scale studies – heat, duration, pressure, moisture content, different substrates	HIGH
Develop bioassay techniques to evaluate the effectiveness of composting treatments	HIGH
What is the survivability of P. ramorum in untreated plant parts. What happens to spore viability as material dries out (leaves, twigs, wood)	HIGH
Evaluate survival potential of sporangia/chlamydospores in "green waste" vs. "dry wood waste"	HIGH
Effect of tarping/solarization of wood piles on viability of *P. ramorum*	MOD
Test cleaning procedures on equipment used in logging and arboricultural operations within a regulated area	MOD.
B. Individual tree treatments, and interface with arboricultural practices	
Test and evaluate fungicide treatments. Preventative and remedial treatments using a broad array of approaches. Use a variety of materials, methods of application, rates of application. Examine side effects, determine efficacy of results	HIGH
Interface of arboricultural practices on *P. ramorum* incidence. (Pruning, fertilization, irrigation, planting method, landscape design, hot water treatments, canker excision)	HIGH
Insecticides for preventative and remedial treatment • Does insecticide treatment prolong tree life? For how long? • How does insect exclusion affect tree failure? • What are residual/non-target organism effects?	MOD
Utility of herbicide treatment of resprouts of infected stems	MOD
What is the effect of burning infected material on long-term viability?	MOD

(How hot, how long to decrease viability?)	
C. Stand and landscape treatments	
Evaluate effect of prescribed burning, including effect of heat and smoke on *P.* ramorum--small-scale, short-term	HIGH
Develop hypothesis and test how manipulating stand structure might affect SOD incidence.	MOD
Develop and test restoration strategies. How does virulence of pathogen change and affect strategies? Role of resistant materials. What is the size/age distribution of infected trees? Apply to a restoration strategy.	MOD
D. Improved monitoring practices, including survey and remote sensing technique	
Develop biologically and statistically reliable sampling protocols for use in declaring an area "disease-free"	HIGH
Develop more accurate maps of the host range and scale-up risk assessments through models	HIGH
Develop and apply risk models to other areas (Eastern U.S., S. America, Europe) and evaluate in terms of export/import issues	HIGH
Develop risk model by plant community	HIGH
Develop an expert system for diagnostics	MOD
Develop methods for automated detection of mortality of oaks and other hosts. Develop classification routines.	LOW
Evaluate pre-visual stress, and time sequence of stress in infected trees	LOW
E. Methods to evaluate potential, and project tree failure	
Develop a phenology model for tree failure that includes: • Characterize rate of tree failure of SOD trees • Do they fail at higher rate than non-infected trees? • How do sequence of symptoms (hypoxylon, beetles) affect failure rate? • Evaluate tree form/architecture, decay, insects, stand type/condidtion? • Develop time series for tree failures? Coordinate with existing tree failure reports – need for additional cross-sectional data	MOD
Interaction of decay organisms with *P. ramorum*. Do they change failure-risk?	LOW
III. DISEASE IMPACTS ON ECOSYSTEM COMPONENTS	
A. Assess impacts of tree mortality and changing vegetation structure on ecosystem communities including elevated ecological threats from factors such as wildfire, flooding, landslides, exotic plant invasions, etc.	
Identify other sources of oak mortality in natural ecosystems and describe contributions of *P. ramorum* to total mortality	HIGH
Develop fire risk model – characterize fuel moisture/amount. Evaluate	HIGH

for different climate zones, vegetation types, etc. Does SOD increase risk?	
Evaluate hydrological effects of stands with SOD--Flooding, siltation, landslides, stream habitat	HIGH
Effects of wildfire risk on wildlife habitat, exotic plant invasion	MOD
How are invasive plant species affected by SOD mortality? How does eradication strategy affect invasive plants versus natural mortality?	MOD
Compare wildlife utilization of infected trees to non-infected sites	LOW
What is effect of SOD on microbial ecology, carbon cycling, soil fungi, mychorrizae?	LOW
IV. ECONOMIC AND SOCIAL IMPACTS	
A. Economic impacts of SOD to trade and movement of forest and agricultural products	
Quantify the cost of quarantine--ornamentals, agricultural products, forest products	MOD
Investigate use of other forest pest economic models for SOD (pitch canker, Dutch elm disease, Asian long-horn borer)	MOD
B. Economic and social impacts to values of individual homeowners and landowners and to communities	
Quantify the economic impact of SOD: • Loss of recreation sites • Decrease in property values • Cost of removal and treatments to homeowners, municipalities • Increase in wildfire risk • Increase in liability from tree failure	MOD

\1 Components of this plan were taken or adapted from earlier planning exercises that involved members of the California Oak Mortality Task Force, research cooperators, regulatory agency personnel, and others. Their input and assistance is greatly appreciated.

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