Sudden Oak Death – an Update

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Introduction

At the 2003 Triennial International Oak Society Conference in Winchester England, I gave an overview of a relatively new disease affecting oaks in California, named Sudden Oak Death (SOD). As described in that paper, this disease is caused by a pathogen - *Phytophthora ramorum* – discovered in 2000. Since then, this pathogen has spread both in the United States and in Europe and threatens not only oaks and tanoaks, but a wide variety of other plant species as well. Because there is still great concern about the SOD pathogen and there have been significant developments in identifying where it occurs, how it moves around, what species become infected, and how to help prevent its spread, I decided to provide another update for this Symposium. I will start with some information contained in the previous paper regarding when and where SOD was first observed and how the pathogen was first identified. I will then discuss significant events regarding this disease in the last three years and what is likely to happen in the future.

Background

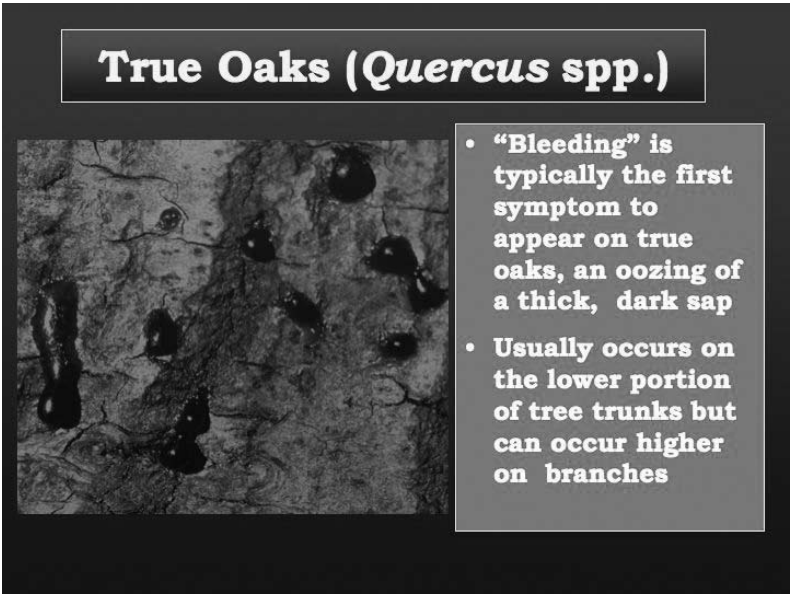
In 1995 a new type of oak mortality was observed in the coastal forests north of San Francisco, California. At first it appeared to only affect tanoak (*Lithocarpus densiflorus*) trees, a species more closely related to chestnuts than true oaks. Within several years, however, coast live oak (*Quercus agrifolia*), California black oak (*Quercus kelloggii*), and Shreve's oak (*Quercus parvula var. shrevei*) were also observed to be dying. No one had ever seen anything quite like this before. First, the new shoots of tanoak would wilt and droop and look like shepherd crooks. Typical symptoms of infected oaks and tanoaks also included seeping of dark brown viscous sap from the lower portions of the main stem, dead discolored patches beneath the bark, extensive tunneling by small insects (ambrosia and oak bark beetles), and the appearance of dark, knob-like fruiting bodies of *Hypoxylon* fungi on the bole. Eventually, the foliage of attacked trees would turn yellow and then completely brown. Dr. Pavel Švihra, a University of California Environmental Horticulture Advisor who was among the first to observe this problem, called this new mortality complex "Sudden Oak Death," or SOD. While the name Sudden Oak Death implies that trees are killed rapidly, it now appears that it can take months, or even a year or two, from the time of the initial infection for death to occur. Also, many more species than oaks are affected by SOD, and many of these other hosts aren't killed by the disease.

For several years it remained a mystery what was causing this new oak mortality. Some scientists originally felt that the insects observed on the sickened trees were the fundamental cause of death, while others suspected that *Hypoxylon* fungi played a primary role. This question remained unanswered until the summer of 2000 when plant pathologists at the University of California isolated a new, previously unidentified species of *Phytophthora* from the cankers of trees exhibiting

these symptoms. Through a series of inoculation tests and the establishment of field plots that were designed to track the development of the pathogen, they were able to determine that this was the primary agent responsible for SOD. The boring insects and *Hypoxylon* fungi play a secondary role, attacking trees that have already been weakened by the *Phytophthora* pathogen, thus hastening their demise.

A serendipitous visit to California by a British scientist further helped shed light on this mysterious new disease. Dr. Clive Brasier, a pathologist from the British Forestry Commission, happened to be visiting Oregon about the same time that this *Phytophthora* was identified as the underlying cause of Sudden Oak Death. Dr. Brasier is a world expert on *Phytophthoras* in wildland forests and traveled to CA to look at the organism under a microscope and in the field. Several months later, when a German colleague showed him a *Phytophthora* that had been causing leaf spots and twig dieback on ornamental Rhododendrons in Germany and the Netherlands since 1993, he thought it looked very similar to the organism he had seen in California. It turned out to be nearly identical and by 2001, this new species attacking plants in both California and Europe was officially named *Phytophthora ramorum* by the European researchers, which translates to "affinity for branches."

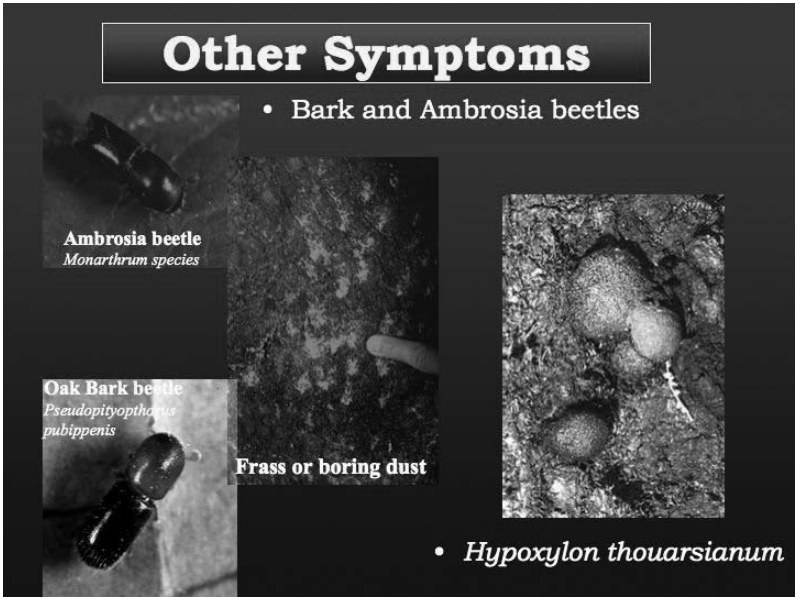
By the end of 2002, this organism had been positively confirmed in 12 coastal counties in California, ranging along a 400 km stretch from the Big Sur area in Monterey County in the south, to Humboldt County in the north. It was also found further north in the southernmost county in Oregon. While some of the most visible symptoms of *P. ramorum* occurred on true oaks and tanoak, researchers were soon finding that other plant species, including popular ornamental plants such as *rhododendron* and *camellia*, were also infected with the disease, but were not killed by it. These species were generally described as "foliar hosts" since the disease infected and damaged leaf and twig tissue, but did not infect boles and did not kill the hosts. It soon became evident that some of these foliar hosts played a critical



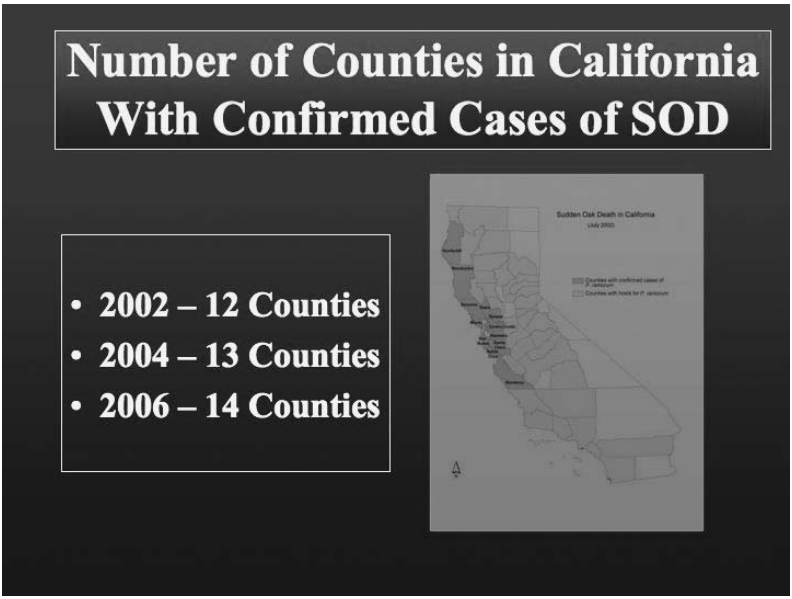
role in the geographic spread of the disease. Unlike most tree hosts that develop cankers, foliar hosts are not killed and therefore can continue to be infectious.

Nursery Infections

One of the most significant occurrences in the last three years regarding this pathogen was the discovery in 2004 of infected camellia plants at two large wholesale nurseries in Southern California. Unfortunately, infected camellia plants from these two locations had been shipped widely throughout the United States. Using trace-forward and trace-backward tests, regulatory agencies tried to determine where camellias from these nurseries had been shipped and whether any that had traveled outside of California had exhibited signs of *P. ramorum*. The results were not encouraging. By the end of the year, infected plants had been found at 176 nursery-related locations in twenty-one states. What was thought to be primarily a California and southwestern Oregon forest problem had suddenly become a national nursery problem that was of grave concern to people nationwide. The first step taken was to destroy infected plants, as well as all known susceptible plants growing in close proximity. All told, more than a million plants had to be killed. Federal and state rules have since been implemented to minimize the likelihood of further spread in the nursery industry. Today annual inspections are required for Oregon, Washington, and California nurseries that ship interstate and have



After a tree is weakened with a *P. ramorum* infection, it is susceptible to invasion by insects and decay fungi. Common secondary organisms are ambrosia & bark beetles, which bore deep into the tree; and *Hypoxylon* fungus, which decays the bark & wood. These organisms are found on many other stressed and dying trees in the forest and are not alone indicative of Sudden Oak Death. They do play an important role in a tree's overall health however and can hasten the death of a tree by further weakening the wood and causing the trunk to snap.



known *P. ramorum*-susceptible plants for sale on site. Although rather drastic and, in many cases costly to those nursery operators that have infected plants, this strategy seems to be working -- at least partially. As of October 2006, 56 nurseries in 11 states have been found to have diseased plants. Furthermore, to date there have been no reported instances in the United States of diseased plants in nurseries (with the possible exception of California) infecting plants outside of the nurseries. That is, there have been no confirmed cases of the pathogen "escaping" into the natural environment.

The Disease in Europe

In Europe, *P. ramorum* has also spread widely and as of 2006, has been confirmed in 15 countries listed below. Almost all of these infections have been in nurseries or garden centers. However, unlike the United States, there have been instances of the pathogen escaping into the wild. For instance, in Cornwall England, confirmed infections were reported on nine trees at three separate sites. Tree species infected naturally in the UK include a non-native American northern red oak (*Quercus rubra),* southern red oak (*Quercus falcata*), European Holm oak (*Quercus ilex*) and Turkey oak (*Q.cerris*). Infections have also been confirmed in native beech (*Fagus sylvatica*), Southern beech (*Nothafagus oblique*), horse chestnut (*Aesculus hippocastanum*), sweet chestnut (*Castanea sativa*), *Eucalyptus haemastoma* Sm. (Myrtaceae), *Cornus kousa* x *Cornus capitata* (Cornaceae), and *Castanopsis orthacantha* Franchet (Fagaceae). All these findings are associated with previous findings of the pathogen in adjacent rhododendron. As a result of concern about the spread of the pathogen into native forests, a massive wildland survey was carried out in the United Kingdom. Fortunately, there were no positive confirmations resulting from this survey. Two isolated forest infections have also been reported in The Netherlands, as well as one in Germany.

Table 1. European countries with confirmed infections in 2006

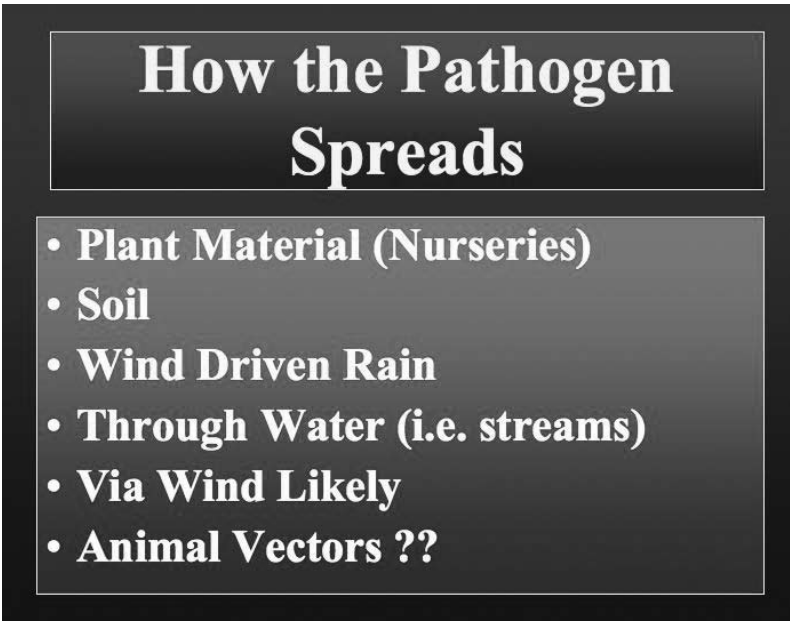
Belgium	Slovenia
Czech Republic	Denmark
France	Sweden
Netherlands	Germany
Poland	Italy
Norway	Switzerland
Spain	Ireland
United Kingdom	

New Hosts Confirmed

Another significant development in the past three years has been the continuing expansion of the number of hosts. In 2002, there were only 14 confirmed host species, including three *Quercus* species and tanoak. By 2004, this number had increased to 68 species and by 2006 it expanded to over 100. Unfortunately *P. ramorum* infects a very wide and diverse set of plants from small herbs to giant conifers. The good news is that very few hosts other than oaks and tanoaks are actually killed by the pathogen, and generally only the foliage or small branches are attacked. The bad news is that by remaining alive, foliar hosts continue to serve as sources of inoculum aiding the spread of *P. ramorum*.

Pathogen Spread

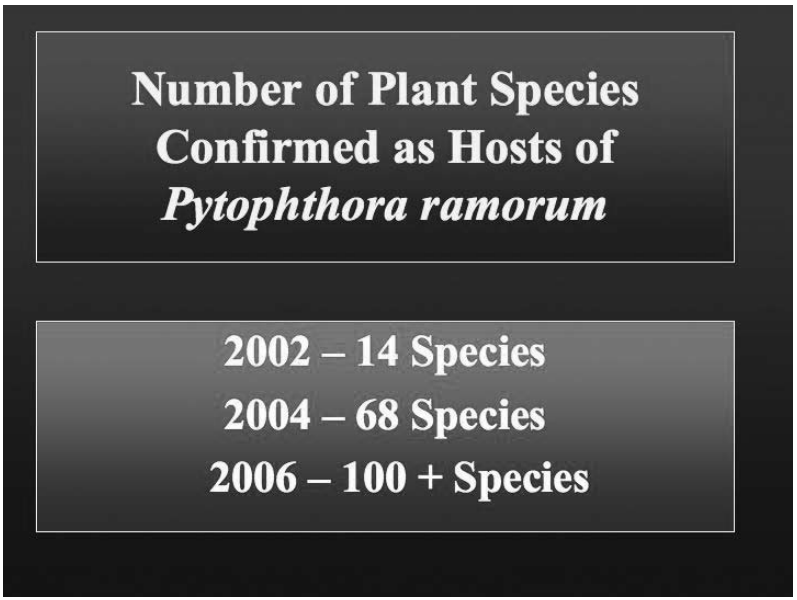
One of the most critical questions that researchers, quarantine officers, and foresters have tried to figure out is how the pathogen spreads. Most *Phytophthoras*

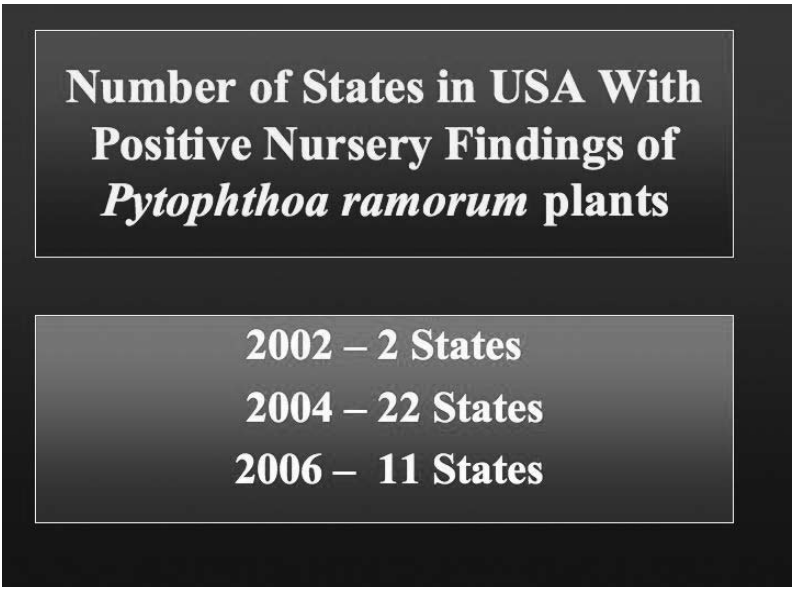


attack roots but until recently, *P. ramorum* had only been isolated from the trunks, leaves, and twigs of plants. While it has been determined that *P. ramorum* can be spread by rain splash and that spores can remain viable both in the soil and in streams that flow through SOD-infested forests, it has not been ruled out whether this particular pathogen could also be transmitted through the air, at least in the presence of water. It is also possible that it is vectored by insects, birds or other animals that come in contact with infected material. However, preliminary studies suggest that these modes of spread are unlikely, or if they do occur, are probably not very important. Other potential pathways, including movement by humans, are also being investigated and research has demonstrated that viable spores can be transported on the soles of hikers' shoes when they walk through infected areas. At present it is believed that in California, California bay laurel (*Umbellularia californica*) plays a key role in the spread of the disease since it is an abundant and widely distributed tree in coastal forests and it readily facilitates pathogen spore production. Removing this species from susceptible, currently uninfected, forests to help curtail spread has been considered. However, bay laurel is a vital component of many forests and removing it may have adverse, but unintended, consequences. Some Native American groups are very concerned about this suggested control strategy since bay laurel is a vital species to their culture for food and medicinal products and are fundamental to some spiritual customs.

Disease Occurrence and Susceptible Species

Several other *Phytophthoras* have also been recovered from host species displaying similar symptoms to *P. ramorum*. Fortunately, these *Phytophthoras* appear to be less virulent than *P. ramorum* and are typically found on isolated trees. Other common oak diseases such as *P. cinnamomi* (crown rot) and *Armillarea mellea* (oak root fungus) can cause similar symptoms and are also probably responsible





for many deaths in the zones where SOD has been detected. It is also important to point out that members of the white oak subgenus of *Quercus* (Section Quercus), which includes both blue oak (*Quercus douglasii*) and valley oak (*Quercus lobata*) in California, and English oak (*Quercus robur*) in Europe, do not appear to be susceptible.

In laboratory pathogenicity trials, however, species of the red oak subgenus (Section Lobatae) from the eastern United States, including northern red oak (*Quercus rubra*) and pin oak (*Quercus palustris*), have been found to be highly susceptible to the pathogen. These species are commercially important in the eastern US, so there is considerable concern that *P. ramorum* could have enormous economic impacts if it spread eastward and infected these species. The habitat in the eastern forests also has susceptible understory species, further increasing the concern. As a result, there have been extensive field studies looking for the disease in native stands in large portions of the eastern US. But fortunately no positive confirmations have been reported.

To date, this disease has been limited to coastal locations in California. However, it has still not been reported further than 80 km inland (not including nurseries). There have been many reported "new" infection areas in the last three years, but the majority of these have been within the previous zone of infection and the northern and southern limits of the disease have not changed substantially. A recent inventory in Monterey County found that hundreds of thousands of trees had been killed in that area alone, so it believed that statewide in California, more than one million trees have succumbed to Sudden Oak Death and at least another million are currently infected.

Pathogen Origin

Since it was first identified, researchers have been trying to figure out where *P. ramorum* came from. Was it introduced to the United States from Europe or visa-versa? Neither of those two scenarios seems likely since the European strain is a different mating type from the US strain. *P. ramorum* also appears to be genetically distant to most of the other 60 *Phytophthora* species. The closest relative appears to be *P. lateralis*, a virulent pathogen of Port Orford cedar (*Chamaecyparis lawsoniana*) known to be present in natural stands in the Pacific Northwest (including northern California) and occasionally on Port Orford cedar stock in nurseries in Europe. At present, based on genetic population structure, researchers believe that *P. ramorum* is relatively new to both the US and Europe, and was likely introduced from a third location, perhaps somewhere in Asia. Some preliminary excursions to look for the disease there have not been successful

Impacts of Sudden Oak Death

As noted in the version of this paper presented in 2003, the potential consequences of high levels of oak tree mortality from *P. ramorum* are severe and far-reaching. There is great concern in California about the safety risk posed by large numbers of dead trees in urban-wildland interface locales and in heavily used recreation areas. Such mortality requires tree removal, which can be costly, as well as dangerous to the tree workers involved. The visual landscape of California, which has large regions of coastal oak woodland, could be altered dramatically. The people of California, as in the United Kingdom and elsewhere, value their oaks dearly, and significant losses of this resource have been emotionally devastating to many. Widespread oak mortality has also had significant impacts to the many wildlife species that are so dependent on coastal oak and tanoak forests for food and shelter. Deer, turkeys, jays, quail, squirrels and acorn woodpeckers are just a few of the many wildlife species that rely heavily on acorns as a food source. And there are numerous other animals that utilize oak woodlands for breeding, or as stopover points during migration.

Ecological processes such as nutrient cycling, storage and release of water, and moderation of soil temperatures are also affected. The loss of large numbers of trees could also result in soil erosion and the invasion of denuded sites by undesirable weed species. Another major concern is the increased risk of fire resulting from the addition of large quantities of highly combustible fuels as the trees die and dry out. Years of fire exclusion have already made some of area where SOD occurs to be at high risk for catastrophic fire, so the addition of more fuels only exacerbates an already volatile situation. Since many areas with high levels of SOD occur at the urban-wildland interface, where homes and businesses are nestled among the trees, concerns of local residents are further heightened.

Treatment

Not surprisingly, there has been an intense demand to find some a treatment that can cure infected trees and/or protect healthy trees from becoming infected. Many large oak trees in urban-wildland interface settings are highly valued by their landowners, and some would pay almost anything to prevent specimen trees from dying. Since the writing of the 2003 SOD update paper, a compound called Phosphonate and sold under the brand name Agri-Fos® has been approved and

registered in California for treating oak and tanoak trees, both as a preventative treatment and for trees recently infected. This chemical has been found to slow pathogen spread on trees that are very recently infected (the canker covers less than 10 % of the circumference of the trunk), have no secondary invaders, and no browning of the foliage. However, it is most effective as a preventative treatment for trees not yet infected but in high-risk situations. Agri-Fos® is not a cure and for severely infected trees, it is ineffective. It is also worth noting that this chemical has limited applicability in wildland settings because the areas where the affected species grow are too large, the number of host plants enormous, and the costs of applying chemicals to thousands of acres would be astronomical. Additionally, there could be serious environmental concerns about applying such pesticides over vast areas of the landscape.

In addition to chemicals, recommendations to landowners in infected regions focus on maintaining tree health. Since native oaks can be adversely affected by summer irrigation, homeowners are encouraged to avoid this practice. They are also encouraged to employ correct pruning practices, and to take steps to minimize adverse impacts to tree roots. Trenching, grading, backfilling, and compacting the area around oak roots should be avoided. To help reduce the spread of *P. ramorum* to uninfested areas, it is also recommended that dead trees be left on-site and, if possible, burned. Equipment used to cut down infected trees should also be sterilized before being used again. Also, hikers and other recreationists in infected regions are encouraged to wash shoes, tires, and even their pets' paws before leaving an infested area, so as to reduce the threat of transporting spores off-site.

Regulation

Both the US federal government and many state governments recognize that the artificial spread of the SOD pathogen is a serious concern and threat. This became especially apparent after the spread of the disease to many other states via nursery plants in 2004. Many states imposed quarantines governing the movement of host material. These rules were designed to limit the artificial spread of the SOD pathogen by curtailing the movement of material that could potentially cause the disease to become established in a new location. To standardize the rules, the federal government developed a federal order for nurseries that superceded state rules.

A number of countries outside the US have also imposed regulations or quarantines regarding the movement of plant parts from species or genera that are confirmed hosts of *P. ramorum*. Presently there are quarantines or rules regulating transport in Canada, the U.K., Australia, Taiwan, South Korea, and many other countries throughout the world. The European Union also has regulations. In some cases, movement of soil that is suspected of being contaminated is also regulated.

What is being done?

In August 2000, the California Oak Mortality Task Force (COMTF) was established to provide a comprehensive and unified approach to address the Sudden Oak Death problem for California. The Task Force has been instrumental in securing funding from a variety of state, federal, and private granting organizations to support research, monitoring, management, and education programs.

The Task Force has co-sponsored two large Sudden Oak Death Science Symposiums and another is scheduled for March 2007. These symposia bring together

the broad array of researchers, regulators, and affected industries from throughout the world addressing this new disease in order to share information and provide a scientific overview of the state of knowledge about *P. ramorum* in forest, woodland, urban, and agricultural settings. These meetings have helped foster closer cooperation between people in various disciplines and geographic areas working on this disease, and have helped inform managers and policy makers about the focus of current research efforts.

Another major activity of the COMTF has been to identify and map locations where SOD has been confirmed and where trees with similar symptoms have been observed. A GIS database of SOD distribution in California is maintained at UC Berkeley and is available for downloading at the CAMFER website (see address at end of paper). This information will be particularly important in determining how rapidly the SOD pathogen is spreading, developing regulations, and managing fire prevention and hazard tree removal programs. Knowing where the pathogen is occurring is also important for quantifying economic and ecological impacts, assisting in early detection, and providing a statistically based estimate of the area impacted by SOD.

The Future of SOD

Research results to date suggest that sporulation is related to rainfall and mild temperatures, and during wet years, an increase in the incidence of the disease is expected. Mortality is greatest during periods of hot weather when trees experience extreme moisture stress. However, it also currently appears that within infested areas, some oak trees in stands may be less susceptible to the disease. This would imply that some trees, even in susceptible hosts and in infested stands, may not be killed by the SOD pathogen. This is good news and suggests that oaks in California may not experience the same fate as American chestnuts (*Castanea dentate*), which were almost, totally eliminated by chestnut blight (C*ryphonectria parasitica*) in the eastern US several decades ago. But we must be cautious since this disease has only been observed for a little over a decade and the responsible pathogen only identified for six years, so we are very early in the game. We can keep our fingers crossed and hope for the best.

Conclusions

While the threat of *P. ramorum* is very serious and should be of concern to people throughout the world, it is encouraging to know that there is broad consensus that resources need to be allocated to minimize the impacts and slow the spread of this pathogen. Compared to research on many other plant diseases, the collaborative efforts by federal, state, and county governments; universities; private industry; and non-profit groups have led to rapid progress on identifying what is causing Sudden Oak Death, determining where it occurs, developing effective tests to confirm if a plant is infected, and developing management recommendations for homeowners, nursery operators, and forest managers. But more work is needed. Hopefully these efforts will succeed and oaks throughout the world, which are such a vital and revered natural resource, will continue to survive and prosper.

For additional information, see the following websites:
http://www.suddenoakdeath.org - California Oak Mortality Task Force
http://kellylab.berkeley.edu/ -- A GIS database of SOD in California
www.CDFA.ca.gov – California Department of Food and Agriculture
http://www.aphis.usda.gov/ppq/ispm/pramorum/ Animal Plant Health Inspection Service
htp://www.defra.gov.uk/planth/pramorum.htm - *P. ramorum* website of the UK Department for Environment, Food, and Rural Affairs
http://www.greenbrae.org/news/sod.html Sudden Oak Death information/ resources
http://fhm.fs.fed.us/sp/sod/sod.shtm USDA Forest Service Sudden Oak Death Forest Health Monitoring