THE PAST, PRESENT, AND FUTURE OF SUDDEN OAK DEATH

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The plant pathogen *Phytophthora ramorum* has been considered a major forest pest since it was identified as causing Sudden Oak Death in 2000. In California alone, it has killed millions of trees (Meentemeyer, 2008) and caused $135 million in property losses to single family homes (Kovacs and others, 2011). Government expenditures on control have reached well over $80 million and current US regulations restrict the shipment of all nursery plants from California, Oregon, and Washington (Frankel, 2008).

Since its discovery, we have learned much about the biology of the pathogen: the modes and vectors of its spread, the species it infects, and how to prevent infections or just manage the resulting damages. For instance, the list of known plant hosts has grown considerably, from a handful of California oaks to more than 125 species, varieties, and cultivars. While other review articles present extensive overviews of the pathogen and its management (Kliejunas, 2010; Rizzo and others, 2011), this article attempts to distill some of the more important developments of the past decade. Specifically, I review the impacts to the horticultural nursery industry, attempts at forest and landscape management in the western United States, the potential usefulness of water monitoring, and the recent development of disease on Japanese larch trees in the United Kingdom.

Figure 1. *Phytophthora ramorum*-positive nursery plants removed as part of quarantine protocols. Photo by Shane Sela, Canadian Food Inspection Agency.

Impacts on the horticultural nursery industry

Phytophthora ramorum causes Sudden Oak Death on tanoaks (*Notholithocarpus densiflorus*) and some oaks (*Quercus* spp.), but it is also responsible for Ramorum foliar blight on most of the other 100+ hosts it infects. Some of the world's most popular horticultural plants – *Rhododendron*, *Camellia*, *Viburnum* – are subject to foliar infections by the pathogen. Because foliar symptoms are usually not fatal, these host plants did not initially receive the same amount of attention as dying oaks. We now know these foliar hosts play a significant role in spreading inoculum and that the movement of nursery plants can introduce the pathogen to new areas.

Little was done at first to stop the commercial movement of nursery plants as long as they were being grown outside of the California counties with forest infestations. That changed suddenly and dramatically when, in early 2004, a large wholesale horticultural nursery near Los Angeles, CA was found with over a million potentially *P. ramorum*-infected camellia plants. This was 300 miles (480 km) from the nearest forest infestation in a climate deemed unsuitable for pathogen activity. Worse still, some of these potentially infected plants had already been shipped around the country. Follow-up inspections found 176 nurseries in 21 states with infected plants. From this incident alone, an estimated 787,842 plants were destroyed under an emergency order by the United States Department of Agriculture, Animal and Plant Health Inspection Service (USDA APHIS).

The USDA then undertook surveys of nursery perimeters (620 locations in 32 states) and forests (404 locations in 18 states) as part of a nationwide monitoring effort. Luckily, at that time, only one additional positive site was found (Golden Gate Park, San Francisco, CA). Regulations were also changed in January 2005 to address nursery stock throughout the entire states of California, Oregon, and Washington. Data show, however, that nurseries and related environments continue to have problems with pathogen infestations (Table 1).

While progress has been made in decreasing the number of positive nurseries, the pathogen still persists in the nursery trade at some level. More worryingly, infected plants from some of those nurseries do occasionally make it out to landscaped yards where the pathogen could spread more freely. In five of the last six years, for example, nursery-related finds have included residential locations, with as many as 7 residential landscape positives in one year alone.

Because of the threat *P. ramorum* poses to oak-dominated forests throughout North America, many state governments have reacted strongly to the possible introduction of the pathogen via the nursery trade. After the 2004 incident, and despite existing federal regulations, 14 states imposed their own stricter importation standards for plant material coming from west coast (California, Oregon, and Washington) nurseries. Additionally, worldwide there are 68 countries for which *P. ramorum* is either on their lists of regulated pests or mentioned in their legislation (Sansford and others, 2009).

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Table 1. The number of positive nursery-related sites per year in the United States. Before 2004, nursery infestations were few in number and thought to occur only in western states. Data courtesy of USDA APHIS.[1] This was from a single county with an existing forest infestation.[2] Of these, 125 positive finds were linked to just one nursery's shipments.[3] 2011 numbers only include data through September.

Year	Number of Positive Nursery-related Sites	Number of US States with Positive Nursery-related Sites
2000 and prior	Zero	
2001	1	CA[1]
2002	Zero	
2003	20	3 (CA, OR, WA)
2004	176[2]	21
2005	99	7
2006	62	11
2007	23	6
2008	28	8
2009	26	11
2010	34	13
2011[3]	25	5

Figure 2. *P. ramorum* eradication efforts in Oregon. Photo by Oregon Department of Forestry. (Photo by Alan Kanaskie, Oregon Department of Forestry).

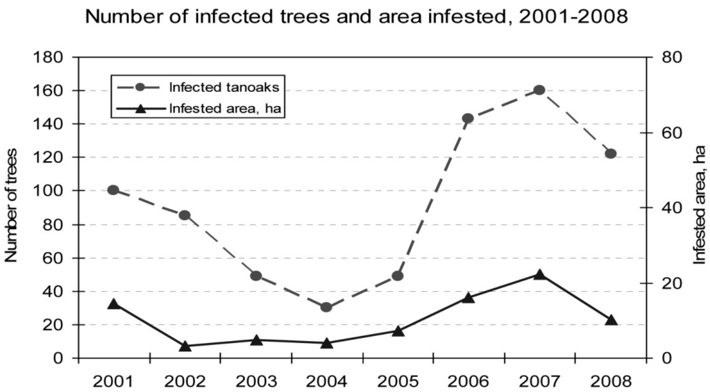

Figure 3. Sudden oak death trends in southern Curry County, Oregon, 2001 to 2009. Reprinted from Kanaskie and others, 2010.

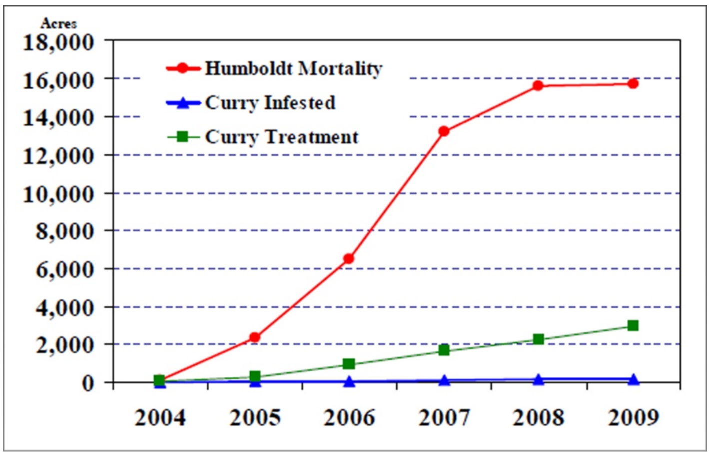

Figure 4. Comparison of acreages infested with and treated for *P. ramorum* in Curry County, Oregon versus the area of trees killed by the pathogen in nearby Humboldt County, California from 2004–2009. Reprinted from Kanaskie and others, 2011.

Forest and landscape management in the western United States

Once the full extent of Sudden Oak Death infestations in California and Oregon forests was determined in 2001, a number of forest management activities began. The most aggressive action has been centered on the infested zone in southwest Oregon. From 2001–2010, Oregon's goal was complete eradication of the pathogen. Due to escalating costs and a lack of funding, however, in 2011 Oregon amended their state regulation to focus only on containment of the outbreak.

Forest eradication treatments in Oregon consist of cutting and burning all infected and nearby host plants, and where permissible, herbicide application to prevent tanoak sprouting (Kanaskie and others, 2010). These efforts generally kept disease levels in check within the original 40 acre (16 ha) quarantine zone, though new finds beyond the treatment perimeter forced its expansion, and by January 2008, it encompassed 162 square miles (42,000 ha; Figure 3).

Then, in fall 2011, a new *P. ramorum* infestation was found 6 miles north of the existing quarantine boundary (12 miles from the nearest infected tree) near Cape Sebastian State Park along the Oregon coast. As required by Oregon regulations, this new site and a three mile buffer zone were added to the quarantine area and subjected to the same restrictions as earlier quarantined zones. It still is not clear how or when the pathogen was introduced at this location.

Despite these setbacks, officials generally agree that their aggressive efforts slowed spread. Kanaskie and others (2011) compare disease progression in nearby Humboldt County, California – 150 miles (240 km) to the south in northern California – as the example of what could have happened in Oregon without eradication attempts (Figure 4).

In California, pathogen spread was extensive and there was no statewide quarantine requiring eradication; a large-scale, integrated management attack proved infeasible. In Humboldt County alone the pathogen continued to spread naturally at an average rate of approximately 1500 acres (600 ha) per year for the past seven years (Valachovic, 2011). Local researchers and managers there made the best of a difficult situation by implementing a variety of smaller management techniques where they had the cooperation of private landowners. These activities were somewhat constrained as they had to fit with the other land use objectives for each parcel; approaches included small prescribed burns and thinning forest stands to remove inoculum-producing hosts (Valachovic and others, 2008; Valachovic and others, 2010).

In other parts of California, management has occurred on an even more piecemeal basis based on grassroots, community efforts (Alexander & Lee, 2010), which may have ameliorated negative effects on a very local level but did not address the large-scale infestation and natural spread within forests. These local control efforts were largely centered on the use of a phosphonate (mono- and di-potassium salts of phosphorous acid) compound, long known to control other *Phytophthora* species in avocado orchards. After researchers found this treatment to be effective at slowing or stopping *P. ramorum* growth in oak trees – provided it was used preventively (Garbelotto and others, 2007) – the fungicide Agri-Fos® and surfactant Pentra-Bark™ were registered by California "for control and prevention of *Phytophthora ramorum*, (SOD) Sudden Oak Death" on oaks and tanoaks.

While other fungicides showed activity against *Phytophthora ramorum*, they were not as effective as the phosphonate and came with greater environmental risks. Additionally, metalaxyl applications can be quite effective on foliar infections but cannot be used routinely, as *Phyotophthoras* are a single gene mutation away from developing resistance to this compound. So, despite not offering a true cure and being far from a perfect preventative treatment in field applications, phosphonate applications remain an important tool to maintain high-value oak and tanoak trees in areas where the pathogen has become established. Immediately upon its acceptance as a treatment, researchers and University Extension agents began training arborists, foresters, land managers, and homeowners on when and how it was best to apply phosphonates. While comprehensive statewide numbers are not available, in one California county at least 4500 gallons of Agri-Fos® were applied to private yards by licensed applicators in 2010 alone (Marin County Agricultural Department, personal communication).

The importance and ambiguity of water sampling

Early detection monitoring for the pathogen continues to be a high priority since spotting small infestations for immediate eradication is one of the best management options available. The USDA-Forest Service flies annual aerial surveys over infested forests, and wildland surveys are done in at-risk forests around California. The most effective and efficient technique, though with mixed results, appears to be watercourse monitoring. *Phytophthora* species are water molds and require moisture for survival; they often live in streams and rivers in addition to plants. Sampling a watercourse provides one sampling location which covers an entire watershed.

A success story of watercourse sampling can be seen in a new forest discovery in central Humboldt County, CA.

Figure 5. A waterway baited with rhododendron leaves to monitor for *Phytophthora ramorum*. Photo by Chris Lee, University of California Cooperative Extension, Humboldt County.

As part of early detection watercourse monitoring in high-risk areas of California, researchers discovered *P. ramorum* in a new Humboldt watershed in mid 2009. This was a site separate from the more southerly infested areas known at the time and the search for the offending forest infestation began in earnest. Within a year, an infected California bay laurel (*Umbellularia californica*) was found approximately 20 miles from the initial water detection. Personnel on the ground continued to look for further infestations and found what is considered to be the original infestation site in a small community near Redwood Creek, where tanoak, bay laurel, huckleberry (*Vaccinium ovatum*), and Douglas-fir (*Psuedotsuga menziesii* var. *mienziesii*) were found infested. While most of these hosts had minor leaf and twig infections, tanoaks of all size classes were found dead. Unlike most other California cases, this relatively early and localized infestation

Figure 6. The Sammamish River in Washington, where *P. ramorum* recovered from water sampling suggests contamination from nearby, upstream nurseries. Multiple surveys have failed to detect the presence of infected upland vegetation along the river. Photo by Gary Chastagner, Washington State University.

provided the chance to implement an eradication treatment to remove the pathogen from the area.

In other examples, especially in areas with many nurseries, monitoring water can bring more questions than answers. In a number of instances, water monitoring near nurseries has shown the pathogen to be present, but no subsequent offending vegetative infestation can be found. One example comes from Washington state, where in June 2007 a water sample from the Sammamish River was found positive for *P. ramorum* but the exact source of the contamination remains unknown (Chastagner, 2011). A second example comes from Mississippi. There, samples just outside of a nursery in late 2007 found DNA matches for the pathogen in both water and riparian willow plants. However, surveys a few months later were positive for water but negative for plants, and all subsequent samples for both water and vegetation were negative (Jeffers, 2011). If anything, these examples show the transient nature of the pathogen and our difficulty in really knowing where (and when) it is in the environment.

Beyond Sudden Oak Death: Sudden Larch Death

Thus far, most attention to the ecosystem damage caused by *P. ramorum* has been focused on the forests of California and Oregon, despite the presence of the pathogen and disease in gardens and landscapes in parts of Europe. Perhaps this was because the situation in Europe seemed decidedly different, with infections limited mainly to *Rhododendron ponticum* and killing relatively few trees – a smaller scale of infestation compared to the forests of North America. That attitude shifted with the finding of infected Japanese larch in the UK, which were dying from bole cankers and spreading the pathogen via twig and needle infections.

In late 2009, researchers with the UK Forestry Commission first reported *P. ramorum* infections on trees growing separate from Europe's usual culprit in spreading disease, the foliar host *Rhododendron ponticum*. Birch (*Betula pendula*) and hemlock (*Tsuga heterphylla*) were found with bole cankers. Japanese larch (*Larix kaempferi*) was afflicted with not only trunk and branch cankers but also dieback on branches, shoot tips, and needles which supported pathogen sporulation. Thus began the search for infested larch in plantations – and it was found, in large number. An estimated half million larch trees were showing symptoms of *P. ramorum* infection (Brasier & Webber, 2010).

Since being identified as a host in August 2009, infected Japanese larch have been found in southwest England, Wales, Scotland, the Isle of Man, and Northern Ireland – two million Japanese larch trees have been felled. The intense scrutiny has identified additional conifer species as hosts (Sitka spruce, *Picea sitchensis*; and Noble fir, *Abies procera*). Concerned about the implications for conifer forests in other parts of the world, researchers in Oregon set about testing the susceptibility of native Western larch (*Larix occidentalis*). Western larch seedlings were planted into infested forests to see if and how symptoms might develop; more than half of these seedlings died or showed from *P. ramorum* symptoms (Hansen and others, 2011).

Figure 7. Larch dieback caused by *P. ramorum* in the UK. Photo by Joan Webber, Forest Research, UK.

Conclusion

After more than a decade of researching and managing Sudden Oak Death and *Phytophthora ramorum*, what have we learned? For one, no matter how much we know, we are always surprised. This is easily exemplified by the case of Japanese larch infections in the UK and the apparent risk to conifers in other parts of the world. We can also see the limits of our knowledge in our stymied attempts to identify sources of water contamination and to relate how those water finds might ultimately lead to infestations on land.

We have also seen that management efforts on the ground can make a difference in keeping the disease from causing much worse damage. This is clear in the comparison of Oregon's eradication efforts with the less aggressive approach in Humboldt County, CA. In a time of shrinking budgets, we may need to prioritize cost-efficient techniques like watercourse monitoring that capture broad snapshots of an area with relatively little cost. However, we must also then be prepared to move quickly once the pathogen is found in order to make the best use of resources while infestations are small.

References

Alexander, J. & C.A. Lee. 2010. Lessons learned from a decade of sudden oak death in California: Evaluating local management. *Environmental Management* **46**: 315–328.

Brasier, C. & J. Webber. 2010. Plant pathology: Sudden larch death. *Nature* **466**: 824–825. DOI: 10.1038/466824a.

Chastagner, G. 2011. An update on *P. ramorum*-positive water in western North America. California Oak Mortality Task Force 2011 Meeting. June 1, 2001 online webinar. http://www.suddenoakdeath.org/news-and-events/comtf-2011-meeting/ Last accessed 23 November 2011.

Frankel, S.J. 2008. Sudden oak death and *Phytophthora ramorum* in the USA: A management challenge. *Australasian Plant Pathology* **37**: 19–25.

Garbelotto, M., D.J. Schmidt, & T.Y. Harnik. 2007. Phosphite Injections and Bark Application of Phosphite + Pentrabark Control Sudden Oak Death in Coast Live Oak. *Arboriculture & Urban Forestry* **33**(5): 309–317.

Hansen, E., J. Hulbert, P. Reeser, W. Sutton, & A. Kanaskie. 2011. Sudden Larch Death? – Larch Susceptibility to *Phytophthora ramorum* in Oregon Forests. 59th Western International Forest Disease Work Conference (WIFDWC), Leavenworth, Washington, USA, October 10–14, 2011.

Jeffers, S. 2011. Challenges of repeat nurseries. California Oak Mortality Task Force 2011 Meeting. June 1, 2001 online webinar. http://www.suddenoakdeath.org/news-and-events/comtf-2011-meeting/ Last accessed 23 November 2011.

Kanaskie, A., N. Osterbauer, E. Hansen, E. Goheen, & R. Schultz. 2011. Sudden Oak Death: Slowing Disease Spread under Tight Budget Constraints. COMTF 2011 meeting, (25 May 2011). Online at http://www.suddenoakdeath.org/news-and-events/comtf-2011-meeting/. Last accessed 04 January 2012.

Kanaskie, A., E. Hansen, E.M. Goheen, N. Osterbauer, M. McWilliams, J. Laine, M. Thompson, S. Savona, H. Timeus, B. Woosley, W. Sutton, P. Reeser, R. Shultz, & D. Hilburn. 2010. Detections and eradication of *Phytophthora ramorum* from Oregon Forests, 2001–2008. Pp. 3–5 in *Proceedings of the sudden oak death fourth science symposium*, S.J. Frankel, J.T. Kliejunas, & K.M. Palmieri (eds.). Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. Gen. Tech. Rep. PSW-GTR-229. 355 pp.

Kliejunas, John T. 2010. Sudden oak death and *Phytophthora ramorum*: a summary of the literature. Gen. Tech. Rep. PSW-GTR-234. Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. 181 p.

Kovacs, K.; Holmes, T.P.; Englin, J.E.; & Alexander, J. 2011. The Dynamic response of housing values to a forest invasive disease: Evidence from a Sudden Oak Death Infestation. *Environmental and Resource Economics* **49**(**3**): 445–471. DOI: 10.1007/s10640-010-9441-y.

Meentemeyer, R.K., N.E. Rank, D.A. Shoemaker, C.B. Oneal, A.C. Wickland, K. Frangioso, & D.M. Rizzo. 2008. Impact of sudden oak death on tree mortality in the Big Sur ecoregion of California. *Biological Invasions* **10**: 1243–1255.

Rizzo, D.M., R.K. Meentemeyer, & M. Garbelotto. 2011. The emergence of *Phytophthora ramorum* in North America and Europe. In Fungal *Diseases: An Emerging Threat to Human, Animal, and Plant Health*. Washington, DC, USA: The National Academies Press.

Sansford, C.E., Inman, A.J., Baker, R., Brasier, C., Frankel, S., de Gruyter, J., Husson, C., Kehlenbeck, H., Kessel, G., Moralejo, E., Steeghs, M., Webber, J., & Werres, S. 2009. Report on the risk of entry, establishment, spread and socio-economic loss and environmental impact and the appropriate level of management for *Phytophthora ramorum* for the EU. Deliverable Report 28. Sand Hutton, York, UK: Forest Research, Central Science Laboratory. EU Sixth Framework Project, RAPRA. 310 p. http://rapra.csl.gov.uk/RAPRAPRA_26feb09.pdf. Last accessed April 2010.

USDA APHIS. 2011. *Phytophthora ramorum* Quarterly Report, March 2011. http://www.aphis.usda.gov/plant_health/plant_pest_info/pram/downloads/updates/2011/1st%20qtr-March2011.pdf . Last accessed 9 December 2011.

Valachovic, Y. 2011. Sudden Oak Death hotspots in Humboldt County. California Oak Mortality Task Force 2011 Meeting. June 1, 2001 online webinar. http://www.suddenoakdeath.org/news-and-events/comtf-2011-meeting/ Last accessed 23 November 2011.

Valachovic, Y., C.A. Lee, J. Marshall, & H. Scanlon. 2010. Forest treatment strategies for *Phytophthora ramorum*. Pp. 239–248 in *Proceedings of the sudden oak death fourth science symposium*, S.J. Frankel, J.T. Kliejunas, & K.M. Palmieri (eds.). Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. Gen. Tech. Rep. PSW-GTR-229. 355 pp.

Valachovic, Y., C.A. Lee, J. Marshall, & H. Scanlon. 2008. Wildland management of *Phytophthora ramorum* in northern California forests. Pp. 305–312 in *Proceedings of the sudden oak death third science symposium*, S.J. Frankel, J.T. Kliejunas, & K.M. Palmieri (eds.). Albany, CA: U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station. Gen. Tech. Rep. PSW-GTR-214.

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