

Forest Treatment Strategies for *Phytophthora ramorum*¹

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Abstract

Although there is no known cure or preventative on a landscape scale for sudden oak death (SOD), the plant disease caused by *Phytophthora ramorum*, a variety of management options has been tested with the goal of developing an integrated program of treatment for the pathogen. This paper presents a first attempt to gather together individual management trials into an overall decision-making tool for landowners contemplating treatments for the disease. It conceptualizes these treatments as a matrix that matches available strategies—some of which are still substantially untested—to management goals for properties or landscapes of varying sizes. The major goals we envision for landowners who are making decisions about *P. ramorum* treatments include 1) minimizing property impacts from the pathogen when it is already established on a property; 2) strategically protecting particular geographic locations, areas of high-quality oak and tanoak resources, or “islands” of old-growth oak and tanoak; and 3) suppressing *P. ramorum* inoculum and limiting its spread on a landscape (or larger) level. For each goal, we consider a number of possible treatment approaches. A key principle for landowners to keep in mind when considering strategies for managing *P. ramorum* is that all treatments should complement long-term goals for the property. In general, the action that should be taken in an area should be appropriate to the size of an epidemic; the most effective treatment programs involve early intervention.

Introduction

There is no known cure or preventative on a landscape scale for sudden oak death (SOD), the plant disease caused by *Phytophthora ramorum*, an invasive introduced pathogen that has been killing trees in California and Oregon since the mid-1990s. However, a range of management options exists for fulfilling a number of *P. ramorum* management goals, from alleviating the impacts of tree mortality on a given property to protecting particular stands from infestation. This paper presents a range of those options in the form of a matrix (table 1) that matches them to typical land management goals related to *P. ramorum* in the hope that land owners and land managers might find it useful as a decision-making tool.

This systematic categorization of treatments is not exhaustive and can be added to or adapted to individual land managers’ needs. Systematically organizing and presenting them in this manner may help counter a persistent perception that in areas where *P. ramorum* is established, or in areas along the California coast in general, there is “nothing that can be done.” The discussion here centers around and proceeds from the understanding that effective treatment depends not only on the motivation to manage, but also on a clear articulation of management goals.

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Setting Goals and Objectives

Effective management of any element of forest structure or function—and this includes disturbance agents like tree pathogens—starts within an understanding of the larger picture in two respects: (1) What are my goals for the forest and/or individual trees on my property? and (2) How does that fit into the context of the ecology of the forest in question? How does typical forest stand development happen over time here, and what are the individual components of that development?

Determining management goals for the landscape can be a daunting task for the landowner or land manager (henceforth “manager”), but it is an essential first step for planning. The condition of any given property in California is most likely the result of past management actions, and managers have many factors to consider, including erosion and water quality issues, sources of fuel, wildlife, aesthetics, and other environmental values (Giusti and Harris 2007). Managers may want to manage their forested properties for occasional or sustained financial return from timber or grazing; maintenance of wildlife populations or habitat for sensitive species; recreation such as horse or ATV riding or camping; scenery; home sites; aesthetics; demonstration of landscape management techniques; preservation of cultural resources or historical sites; or a variety of other purposes.

Understanding the ecology of local forests provides essential knowledge that narrows the range of management actions available to the manager. Managers should understand how the physical characteristics of the landscape affect plant growth and succession; how vegetation structure influences fire risk and erosion hazards; which wildlife species depend on which other species (plant, animal, and fungal); which species are native and which are introduced; and so on. Conducting an inventory and assessment of the property and its variety of habitat conditions, while time-consuming, is important to establish informed criteria for making management decisions. Managers can consult trained professionals, such as consulting foresters or rangeland managers, University of California (UC) Extension advisors, and California Department of Forestry and Fire Protection (CAL FIRE) service foresters for help in understanding the range of options.

Putting *Phytophthora ramorum* in Context

Returning to the problem of managing *P. ramorum*, then, becomes clearer once the manager has articulated general management goals and limited the management options available on the property. However, it also becomes more complex as the manager realizes that he or she must fit *P. ramorum* into a context of other, simultaneous management goals. Fortunately, many of these management goals are complementary to the options available for *P. ramorum* management. Thinning susceptible host trees such as tanoaks (*Lithocarpus densiflorus*) to discourage pathogen persistence, for example, may hasten the development of historically Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) dominated forest stands into a late-seral condition characterized by a stratum of very large, tall Douglas-firs over a secondary canopy of a few large hardwoods—desirable for many publicly managed forests. Improving roads to control erosion often has the side benefit of eliminating muddy areas, lessening the chance that *P. ramorum* inoculum will be moved off-site on vehicle tires. Constructing shaded fuelbreaks to provide fire control points and reduce fuel ladders along strategic roads and ridgetops can open up the stand, reducing both humidity (which *P. ramorum* needs to survive and reproduce) and absolute numbers of *P. ramorum* hosts.

Phytophthora ramorum management must also be seen within the context of larger regional vegetation ecology. The palette of management actions available in Humboldt County, where tanoak is the primary host to sustain lethal infections, differs from the actions available in coast live oak (*Quercus agrifolia*) dominated areas of Monterey County. Options in both of these example areas will differ from those available in southwestern Oregon, where the presence of California bay laurel (*Umbellularia californica*) does not drive disease spread in the same way that it does in California.

Testing Management Options

A number of researchers have been testing a variety of management options for *P. ramorum* (Garbelotto and Schmidt 2009, Garbelotto and others 2007, Goheen and others 2002, 2004, Kanaskie and others 2006, Swiecki and Bernhardt 2007, Valachovic and others 2008). Taken together, and keeping in mind the regional differences mentioned above, they form the beginnings of an integrated, adaptive program to learn how best to treat forest stands infested by *P. ramorum*. These treatments are in a variety of stages of testing, and even ones that have been shown to be effective continue to undergo revision as our knowledge of *P. ramorum* biology advances.

Table 1 summarizes some representative available treatments (including treatments both tested and untested) according to the primary *P. ramorum* management goal on that property. For simplicity, we have defined three common management goal scenarios: (1) minimizing property impacts from SOD; (2) strategic protection of tanoak islands, old-growth tanoak, or particular geographic areas; and (3) suppression of *P. ramorum* and limitation of spread. The first scenario presupposes active disease on the property, so that managers want to limit secondary problems accruing to tree mortality, such as safety and fire risks. The third presupposes concern for an area landscape larger than most individual properties. The Oregon eradication attempts belong to this category.

The manager should keep in mind at least two related points when reviewing the list presented here. First, the options presented here do not exhaust the range of treatment options for *P. ramorum* that have been proposed, are being tested, or have been shown to be effective in certain situations. Some treatments that are unique to a limited set of site variables (such as implementing host-free barrier zones) have not been presented here. Second, the landscape where many of these treatments have been tested is the north coast of California, where tanoak is the primary species to sustain lethal infections and large tracts of uninfested property exist that both represent ideal habitat for *P. ramorum* infestation and contain high-quality resources that warrant large-scale protection efforts. Because of this, our discussion limits itself to the range of site conditions present on the north coast. However, most of these treatments have analogues in the other regions of California and Oregon where *P. ramorum* is present or can be adapted to fit those regions.

Table 1 Matrix of *P. ramorum* management goals and possible treatments, with lead researchers for treatments

Goal	Minimizing Property Impacts from Sudden Oak Death	Strategic Protection of Oak and Tanoak Islands, Old-Growth trees, or Particular Geographic Areas	Suppression of <i>Phytophthora ramorum</i> and Limitation of Spread
	Dead tree removal [¶]	Manual removal of California bay laurel only ^{*†}	Manual removal of bay laurel and tanoak (+/- prescribed underburning) [*]
	Reforestation	Agri-Fos [®] application ^{*.†.‡}	Modified fuel hazard reduction removal (+/- California bay girdling) [§]
Treatment	Maintain some tanoak with thinning (manual or by Agri-Fos [®]) [¶]	Combination of manual removal of bay laurel and Agri-Fos [®] application [¶]	Herbicide host removal (California bay laurel and tanoak) [*]
Combination treatments to address site specific goals			
<p>*Tested by Y. Valachovic and others in Del Norte, Humboldt, and/or Mendocino Counties †Tested by T. Swiecki and others in Bay Area and surrounding coastal California area ‡Tested by M. Garbelotto, D.J. Schmidt, and others in Bay Area and surrounding coastal California area §Tested by numerous researchers ¶Still untested</p>			

Which Species to Treat?

Most treatments target California bay laurel and tanoak because these are the two host species known to most readily support *P. ramorum* sporulation in California wildlands (Davidson and others 2001, Davidson and Shaw 2003, Maloney and others 2005), allowing for subsequent spread to other trees. Little is known about the ecology of these two species or their appropriate management. We do know that both have increased in abundance over the past century because of fire suppression and the tanbark industry (Meentemeyer and others 2008, Stuart and Stephens 2006, Tappeiner and others 1990). Each species has an important ecological role; an integrated approach to disease management will not advocate for widespread removal of either species.

Testing Treatment Effectiveness

Many treatment studies are still in progress, with results that are more suggestive than conclusive. A number of methods exist to assess treatment effectiveness, most of them based on monitoring treated stands for pathogen presence at various times after treatment. These methods include (1) periodic, usually annual, return visits to established monitoring plots to survey for the beginnings of new disease symptoms; (2) spore traps consisting of water-filled buckets with floating rhododendron or California bay laurel leaves to bait any pathogen spores that move through the air and fall into the buckets in wet winter and spring weather; and (3) baiting *P. ramorum*

spores from soil collected at the treatment site. However, managers should not forget the qualitative aspects of evaluating treatments, including the satisfaction of the other, complementary management goals mentioned earlier in this paper. For example, at a ranch in Mendocino County where dead and infected trees are removed yearly to improve aesthetics and reduce fire hazard, the owners assume that *P. ramorum* will persist on-site, even if at low levels, so the look of the forest, the wildlife it attracts, and the alleviation of safety hazards serve as their metrics for evaluating the treatments implemented by the property foresters.

Treatments

Goal: Minimizing Property Impacts from Sudden Oak Death

These strategies seek to cope with the continued presence of *P. ramorum* by addressing its impacts in such a way that fire hazard is lessened, the forest is revegetated appropriately, and aesthetic values are maintained.

Dead Tree Removal–

Various studies designed to answer questions about the contribution of SOD to hazardous fuel amounts and configurations are underway (Lee and others, these proceedings). These answers could help set guidelines for how long the fuel risk will be of concern and how aggressively landowners should manage dead tree removal on their properties. Treatments that remove dead trees also help to alleviate safety (among other) concerns.

Reforestation–

Landowners throughout California have numerous questions about how and what to replant to replace tanoaks and true oaks killed by *P. ramorum*, but little research has been done to answer them. In each situation, it is also important to know what regenerates naturally after *P. ramorum* kills on-site oaks and tanoaks. Appropriate replanting will vary depending on the property manager's future desired condition for the landscape and whether new seedlings will survive or be killed by new waves of *P. ramorum* without removal of nearby infectious California bay laurel trees.

Tanoak Component Retention–

Managers might want to maintain some specific numbers of tanoak trees, or particular individual trees, on site for several reasons, including maintaining complexity of canopy layers, preserving old-growth tanoaks, or supporting wildlife. This sort of treatment may be more warranted in tanoak stands than in true oak stands because *P. ramorum* is more likely to kill a greater proportion of the stand in the case of tanoak (Garbelotto and Schmidt 2009) and because tanoak forests are generally much more dense than true oak forests or woodlands. Focusing on key specimen trees, thinning small neighbors of large trees that the manager desires to retain, or treating specimen trees with the systemic fungicide Agri-Fos® (see Agri-Fos® Application in Forests, below) long in advance of pathogen arrival at the site are all options to achieve this goal. Trials now being designed in the north coast will be conducted at varying levels of tanoak retention to test how much tanoak can be left on site while still providing protection from *P. ramorum*.

Goal: Strategic Protection of Tanoak Islands, Old-Growth Tanoak, or Particular Geographic Areas

If property managers wish to protect certain areas or groves of tanoak or true oak trees, they can introduce specific chemical barriers (see Agri-Fos[®] Application in Forests, below) for tanoaks or true oaks (the main lethal hosts of the pathogen) or possibly remove bay laurel (the main reproductive platform for the host). In California, bay laurel consistently becomes infected in a given area months to years before tanoaks begin to die. While widespread removal of California bay laurel is not advocated, it may be possible to protect areas by some strategic removal, especially where California bay laurel density is low and/or where the trees are just becoming established.

Manual Removal of California Bay Laurel Only–

Since California bay laurel is the main transmitting host, it may be possible to slow the spread of the disease by removing California bay laurel only. This is similar to the approach utilizing removal of both California bay laurel and tanoak, except that because smaller numbers of trees are felled, labor and costs are much less. It is sometimes possible to leave entire trees to decay on the ground unprocessed, which can reduce costs even more, although lopping and scattering the fine branches is recommended to speed decomposition and alleviate fire risk. Again, California bay laurel removed in this manner will sprout. As mentioned above, it is not usually necessary to remove all California bay laurel trees on a given property; rather, *strategic* removal is advised. California bay laurel removal projects should take advantage of the distribution and sizes of California bay laurel trees across the landscape (and in relation to the locations of oaks and tanoaks). The manager may find that it is too expensive or environmentally costly to remove large, old California bay laurels.

Agri-Fos[®] Application in Forests–

The systemic fungicide Agri-Fos[®] has been shown in the laboratory to be effective in preventing infection in uninfected tanoak and oak trees to which the fungicide is applied (Garbelotto and others 2007, Garbelotto and Schmidt 2009). Agri-Fos[®] is the trade name for phosphonate, a neutralized form of phosphorous acid (H_3PO_3). Although it was initially investigated as a potential fertilizer, phosphonate soon became recognized for its systemic fungicidal qualities (Bender 2005). Systemic fungicides work by traveling through the tree's transport system to all parts of the tree; phosphonate fungicide stimulates the production of defensive chemical compounds and thus the tree's resistance to pathogen invasion and pathogen growth. Agri-Fos[®] has mostly been used until now to protect individual landscape trees of concern. Current studies are transferring the existing laboratory- and orchard-based trials outdoors to test the efficacy of the fungicide on larger groups and landscapes of tanoak and oak trees. The efficacy of Agri-Fos[®] against *P. ramorum* lasts for about 2 years (Garbelotto and Schmidt 2009), necessitating repeated booster treatments indefinitely.

Combination of Manual Removal of California Bay Laurel and Agri-Fos[®] Application–

While not field tested, this combination could potentially suppress *P. ramorum* sporulation more than either technique alone. This may be an effective technique for application to stands of trees in areas where a strategic barrier is desired, such as the outer edges of the stands or on ridgetops.

Goal: Suppression of *P. ramorum* and Limitation of Spread

In wildlands where *P. ramorum* presence is very limited and the pathogen infests small, isolated areas, a set of tools exists to attempt to suppress spore production, modify the environment to discourage pathogen persistence, and make long-range pathogen “jumps” to other, uninfested areas more unlikely.

Manual Removal of Tanoak and California Bay Laurel--

This treatment, as it has been tested, focuses on the removal of both major hosts that support *P. ramorum* sporulation in north coast forests. It involves cutting all tanoak and California bay laurel trees and piling and burning the foliage and small branches. Large branches and trunk wood can be left on site or removed for use as firewood (if done with caution and under guidance so that potentially infected materials do not leave the generally infested area). This is one of the most costly (\$1500 to \$3000/acre) (Valachovic and others 2008), labor-intensive, and time-consuming silvicultural approaches to controlling SOD. It is also the most thorough, especially when combined with prescribed underburning to remove seedlings and infected foliage. Without further treatment, tanoak and California bay laurel stumps will re-sprout and grow vigorously.

Modified “Fuel Hazard Reduction” Removal--

This approach mimics the shaded fuelbreaks created by fuel hazard reduction projects in strategic locations around the American West. A large proportion of small trees and underbrush are removed to increase spacing between trees, clear out the understory, and reduce fuels that could move fire vertically into tree canopies. It is hoped that this treatment might reduce humidity in the forest understory and so make it more difficult for the spores of the SOD-causing pathogen to persist. Along with some unspecified proportion of tanoak trees, this treatment should attempt to remove all California bay laurel trees within the treatment area. Costs vary by stand condition, but should generally be less than the removal of all tanoak and California bay laurel trees as described in the prior prescription. One difficulty is that large California bay laurel trees, which are not normally removed in a typical shaded fuelbreak situation, can be costly and time-consuming to cut down and process; killing the tree in place by girdling has been tried, but without success. The public is already generally accustomed to this mode of forest management, which could render it more acceptable to use than some other techniques.

Herbicide Host Removal--

Killing tanoak and California bay laurel with herbicides is much cheaper (\$200 to \$250/acre) and less time-consuming than manual removal. It also carries the advantage of keeping the stumps of this host from re-sprouting, thus removing the possibility that those sprouts will be reinfected (Kanaskie and others 2006). However, it will increase fuel hazard as standing trees die, retain their foliage for a short while, and dry out before falling and decomposing. To alleviate this concern, it is also possible to manually cut and process trees and then treat the stumps with herbicide to prevent resprouting. Herbicide use is not acceptable to all landowners. Additionally, the standard herbicide treatment used in forestry applications (imazapyr) has proven insufficient to rapidly defoliate California bay laurel; follow-up herbicide efficiency trials are underway in Humboldt County.

Summary

Other treatments or treatment combinations may become possible as new ideas present themselves. All treatments should complement the long-term goals of the landowner for the property and can include other silvicultural elements such as replanting or pruning. The treatments presented here are unlikely to eradicate the SOD pathogen; such an eradication program requires sustained effort and repeated treatment entries into forest stands over many years. In general, the action that should be taken in an area should be appropriate to the size of the epidemic; the most effective treatment programs involve early intervention (Gilligan 2007). All actions designed for SOD management should be undertaken after gathering appropriate information, seeking technical assistance and advice, thinking carefully about the likelihood of success, and weighing the possible benefits to resources against the possible costs.

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