Suppression of *Phytophthora ramorum* Infestations Through Silvicultural Treatment in California's North Coast[1]

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Abstract

In 2006, three forested sites infested with *Phytophthora ramorum* in Humboldt County, California were subjected to different combinations of treatments designed to reduce inoculum and control spread. One treatment, consisting of removal of all California bay laurel (*Umbellularia californica* (Hook. & Arn.) Nutt.) and tanoak (*Notholithocarpus densiflorus* (Hook. & Arn.) Manos, Cannon & S.H. Oh) trees, was applied at all three sites, and other treatments were applied as case studies at single sites. The sites were monitored for 6 years. Results to date suggest that the treatments that involved the cutting of California bay laurel and tanoak substantially reduced *P. ramorum* inoculum levels. However, in treatment areas where scattered California bay laurel trees were inadvertently missed because of a restricted time window for operations, a relatively minor component of residual California bay laurel trees may have become infected following treatment and/or harbored prior cryptic infections and subsequently spread *P. ramorum* to regenerating California bay laurel and tanoak. The data suggest that pathogen reestablishment in these sites was driven by both incomplete treatment application and spread from adjacent, untreated stands.

Keywords: *Phytophthora ramorum*, silvicultural treatment, infestation suppression

Introduction

One major goal of *Phytophthora ramorum* research is to provide scientifically tested and effective management strategies to help land managers and landowners control the pathogen and its effects on properties and landscapes of varying sizes (Valachovic et al. 2010). Various large-scale management projects have been undertaken in Oregon (Goheen et al. 2004, Kanaskie et al. 2009), the United Kingdom (Webber et al. 2010), and northwestern California (Valachovic et al., Novel approaches to SOD management in California wildlands: A case study of eradication and collaboration in Redwood Valley, this Proceedings). These projects have yielded varying levels of success, but much useful knowledge. Similarly, researchers have identified several effective approaches for protecting individual trees from *P. ramorum* infection (Garbelotto et al. 2007, Lee et al. 2011, Swiecki and Bernhardt 2010), including application of phosphite systemic fungicide to individual trees to prevent infection and removal of California bay laurel, the main wildland carrier host that supports high sporulation of the pathogen.

The field experiments described in this paper were designed to help understand the efficacy of a range of treatment techniques for controlling or containing *P. ramorum* at the scale of the small- to medium-sized individual property in order to minimize pathogen impacts and protect other stands of trees or other properties from pathogen invasion. At this scale, protection of individual trees by phosphite may be prohibitively expensive. Similarly, some silvicultural techniques may also be too costly while others may not fit all landowners, such as the use of herbicides to kill host trees or

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control stump sprouting. The properties in this study await finer scale data collection in summer 2012, but the preliminary results presented here suggest some fruitful information for *P. ramorum* management.

Methods

Study Sites

Southern Humboldt County lies within a Mediterranean climate zone (warm, dry summers and cool, wet winters), and although our study sites range from ~13 to ~18 mi (21 to 29 km) inland from the ocean, they are considerably influenced by fog and maritime wind because of several southeast-to-northwest flowing rivers that serve as corridors to the sea. The area receives an average of 1700 mm of precipitation per year, almost all coming between November and May; average maximum temperature is 19.8 ˚C, while average minimum temperature is 6.6 ˚C (WorldClimate 2012). The underlying geology of most of the region consists of sedimentary marine deposits of the Franciscan Formation, which have contributed to the formation of inceptisols and ultisols that are slightly to moderately acidic, gravelly to loamy in texture, and well suited to timber production (Natural Resources Conservation Service 2012a, b). Vegetation types within the study areas fall within the redwood (*Sequoia sempervirens* (D. Don) Endl.) and Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco)-tanoak (*Notholithocarpus densiflorus* (Hook. & Arn.) Manos, Cannon & S.H. Oh) alliances (Sawyer et al. 2009); these two forest types intergrade into each other at varying elevations and on varying slope positions depending on local topography.

Treatments took place on three sites in southern Humboldt County, California: "Connick Creek," "Jay Smith," and "Salmon Creek." The Jay Smith site is owned by California State Parks and, while not developed for recreation, is managed for resource values such as old-growth redwood habitat. The other two sites are privately owned parcels and are managed for a variety of uses. The extent of detectable *P. ramorum* infestations at each site was delineated by ground surveys in 2005, and treatment areas were then outlined by creating a ~100 m buffer from all locations of symptomatic hosts.

Treatments

Because of landowner objectives, funding, and practical constraints, only one treatment (complete removal or cutting of all California bay laurel and tanoak) was replicated across sites. A few patches of bay laurel were inadvertently left within the treatment area at Jay Smith because of harvest restrictions associated with marbled murrelet (*Brachyramphus marmoratus*) nesting season prevented continued operations and a final clean-up of the site. A list of experimental treatments follows:

1. Complete California bay laurel and tanoak removal by chainsaw (Connick Creek and Jay Smith) or by herbicide of standing trees without cutting (Salmon Creek only).
2. Same as (1), but with subsequent broadcast burning (Jay Smith only).
3. Removal of California bay laurel alone by chainsaw (Connick Creek only).
4. Girdling of large California bay laurel along with fuel hazard reduction (FHR) thinning (Connick Creek only).

Data Collection

Treatment units varied in size within and among sites. For each unit, enough 0.04 ha (0.1 ac) randomly located circular plots were established to yield a 5 percent sample of its area, and plots were also established in adjacent untreated areas. Within plots, all trees >12.7 cm (5 in) diameter at breast height (DBH) were tagged and the trees and their basal sprouts were examined for *P. ramorum* symptoms. Sprout clumps and saplings were enumerated and examined in one 0.02 ha (0.05 ac) circular subplot within each of these plots, and seedlings were enumerated and examined within four 0.004 ha (0.01 ac) subplots per plot. Plots were established in January through May of 2006; the first plot surveys were conducted pre-treatment in 2006, and similar surveys were conducted annually in 2007 through 2011. In post-treatment surveys, California bay laurel and tanoak sprouts from stumps of treated (removed or herbicide-treated) trees were also examined. Where symptoms were found, at least one tissue sample was taken from each symptomatic cohort (trees, saplings) where possible, excluding tissue from bole cankers.

A series of transects was also surveyed at Jay Smith in 2011. Transects were 6 m (18 ft) wide and spaced 80 m (262 ft) apart running through the treatment units and from 0 to 150 m (492 ft) outside the treated area (depending on land ownership). Within each transect, symptomatic hosts were recorded, and one to several tissue samples were collected where symptoms were present; multiple samples were taken where multiple symptomatic individuals occurred within a ~3 m radius. Each time a sample was collected from symptomatic tissue(s) in a ~3 m radius, surveyors then moved 15 m (50 ft) further along the transect and resumed surveying for symptoms. All tissue samples were plated on PARP medium for identification of *Phytophthora* spp. To complete fine-scale data collection at these sites, similar transects will be installed at Connick Creek and Salmon Creek in 2012. Along these transects and those at Jay Smith, details on growth type, size, and symptoms of all California bay laurel and tanoak individuals will be recorded, and tissues will be collected from every symptomatic individual encountered.

Data Analysis

Data analyses were conducted in SAS® version 9.3 (SAS Institute, Carey, SC). For logistic regression, the LOGISTIC procedure was used where data representing overall infection response (yes/no) across the entire study were modeled. Individual survey year infection data were modeled with survey year as an effect, and plots were considered repeated measure subjects, using the REPEATED option in the GENMOD procedure. Only predictor variables satisfying an alpha level of 0.05 in chi-square tests are presented. The LOGISTIC procedure was used to calculate the area under receivership operator curves (ROC scores) of model predictions.

Results

Based on logistic regression in which the response variable was whether or not a plot had *P. ramorum* detected at any time during the study, the effect of treatment (yes/no) had a significant negative relationship to infection probability (fig. 1). Probability of plot infection ranged from 14 to 36 percent for the different treatment types, as predicted by logistic regression (model ROC score = 0.74). Addition of a site by survey year interaction term to the treated (yes/no) predictor resulted in a model with good discriminatory power (ROC score of 0.81 vs. 0.64 for model shown in fig. 1) and reflects that infection levels increased strongly in 2010 and 2011 and varied among sites in some survey years (fig. 2). Logistic regression of 2011 Jay Smith transect data added to cumulative plot sample data showed that having uncut California bay laurel trees within 50 m of a sample significantly increased its probability of becoming infected—by about 20 percent (n=271 samples). By summer 2012, it had been confirmed that the vast majority of patches of residual California bay laurel trees within the treatment units and those examined outside of the treatment area (up to ~100 m outside treatment unit boundaries) were infected with *P. ramorum*.

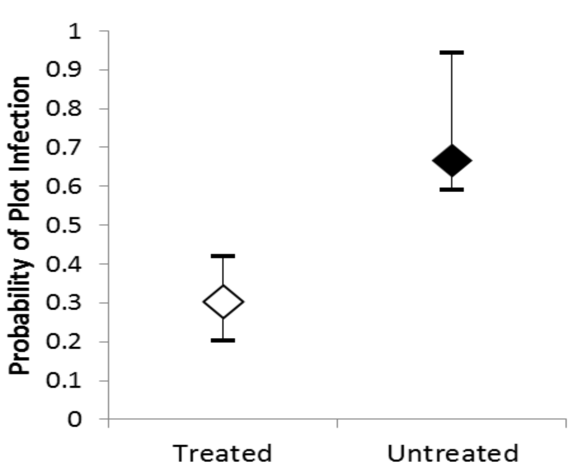

Figure 1—Probability of *Phytophthora ramorum* detection in plots at any time during the survey period, as predicted by logistic regression model. Error bars represent 95 percent profile likelihood intervals.

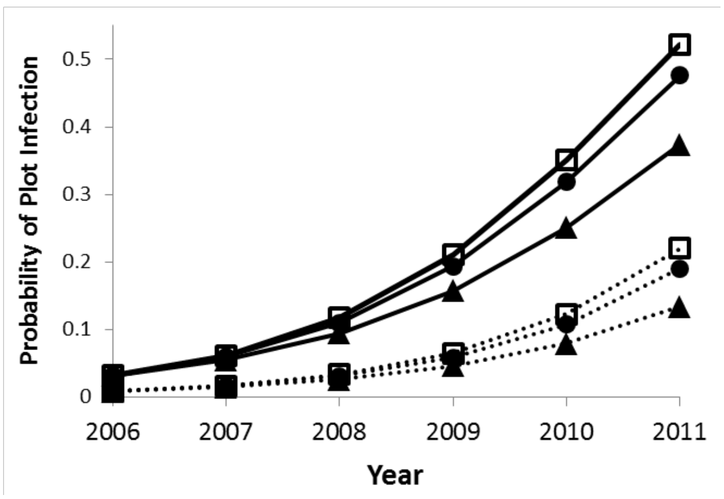

Figure 2—Probability of *Phytophthora ramorum* detection in plots by survey year and site, as predicted by logistic regression model. Squares: Jay Smith, Circles: Salmon Creek, Triangles: Connick Creek. Solid lines: untreated plots, dotted lines: treated plots.

Tanoak mortality was substantial in plots in untreated areas, averaging from 20-24 percent of tanoak trees at the three sites. In the California bay laurel removal and FHR treatments at Connick Creek, the probability of *P. ramorum* detection was not higher than in California bay laurel-tanoak removal treatments; tanoak mortality was 12 percent and 7 percent in these treatments, respectively. Tanoak trees showed many symptoms consistent with the pathogen, but retrieval of viable symptomatic tissues was rarely possible. Surprisingly, none of the California bay laurel trees girdled in the FHR treatment died.

Discussion

While the treatments did not fully control the pathogen, it is promising that they reduced the probability of plot-level infection by an average of 55 percent. Complete pathogen control in these study sites was confounded by several factors. First, it became obvious in 2007 that the pathogen had already become established in the untreated areas surrounding the treatment units that were believed to be free of the pathogen in 2006. Infestations in these areas may have been present in 2006, but were cryptic in nature, and inoculum from more distant sources continued to arrive at the sites. Second, the few residual, uncut California bay laurel trees in treatment units at Jay Smith, along with the significant number of California bay laurel outside the treatment area, likely became infected from outside sources after treatment and may have had prior cryptic infections and/or facilitated subsequent local spread to regenerating California bay laurel and tanoak seedlings and stump sprouts in treatment units. Lastly, the herbicides used at Salmon Creek did not kill trees quickly; it took until 2009 before even half of the trees had died. This left a strong inoculum source within the treatment units to directly infect regenerating hosts in the understory. Subsequent herbicide trials have been completed, and effective approaches have been established to rapidly kill standing bay and tanoak trees (see Valachovic et al., Novel approaches to SOD management in California wildlands: A case study of eradication and collaboration in Redwood Valley, this Proceedings).

Results presented here are preliminary because transect surveys have not been completed at all sites; plot-based surveys were less effective in detecting pathogen reinvasion, likely due to spatial patchiness of infections within and outside the treatment units. This is evidenced, for example, by the fact that 2011 transect surveys at Jay Smith detected many infected individuals in one section of a treatment unit that, from permanent plot data, appeared to have very low infection levels. Due to the randomization of plots within treatment units, the infested section of the treatment unit did not include any permanent plots by chance. The converse was also true, as another unit at Jay Smith contained several plots clustered near residual bay laurel trees that became infected, and understory individuals in these plots also became infected. Further transect-based surveys in 2012 will add to this currently incomplete picture. These transect data will support more complete spatial analyses and will provide better understanding of the relationship between proximity to untreated California bay laurel trees and pathogen reestablishment in treatment areas.

Due to the fairly regular distribution and frequency of tanoak in areas adjacent to the treatments and within treatment units that did not include removal of all California bay laurel and tanoak, it was not feasible in this study to examine effects of proximity to live tanoak trees on infection probability. However, the high tanoak mortality in these areas, along with the apparent spatial dependence of understory infections on diseased canopy tanoak trees in Oregon (Peterson, Testing the importance of understory *Phytophthora ramorum* as a means of primary disease establishment in Oregon forests, this Proceedings), suggests that in the absence of tanoak removal, a substantial proportion of tanoak trees will be lost in infested zones and that the disease will be further spread to understory hosts.

Even with limitations in the data presented, results from the Jay Smith site, in particular, reinforce the importance of California bay laurel as the important driver of pathogen spread and establishment (Davidson et al. 2008) and of the need for *P. ramorum* management to include thorough treatment of California bay laurel. In southern Oregon, the pathogen has spread more than 100 to 300 m from the nearest known infection-related mortality in the previous year (Hansen 2008). These results suggest treatments should extend more than 100 m from the nearest infected tree to be most efficient in reducing pathogen populations and continued spread. The exact size of the area to be treated outside of the boundaries of observed infestations (e.g. 100, 200, 300 m buffers) necessitates further field and modeling research.

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