

# Management of *Phytophthora ramorum* at Plot and Landscape Scales for Disease Control, Tanoak Conservation, and Forest Restoration – Insights From Epidemiological and Ecosystem Models<sup>1</sup>

João A.N. Filipe,<sup>2</sup> Richard C. Cobb,<sup>3</sup> Maëlle Salmon,<sup>4</sup> David M. Rizzo,<sup>3</sup> and Christopher A. Gilligan<sup>2</sup>

## Introduction

*Phytophthora ramorum* has continued to spread in forests in the western United States, the United Kingdom, and the Republic of Ireland, and continues to challenge vegetation and ecosystems in temperate regions (Brasier and Webber 2010, Grünwald et al. 2012). Disease management in the wild has been applied with some success in localized outbreaks in northern California and in Oregon, and in trial treatments; for example, using host removal and host protection (phosphonate application) at plot and stand levels. However, there is still very limited observational data on the efficacy of these treatments, both at the individual-tree level and at community and landscape scales. A central question to decision-making and the deployment of resources, is how to design management strategies that have the greatest and most durable impact and the least expenditure. In order to address this question, we need to gain a better understanding of which treatments work best for a specific scale, forest composition, and set of resources available. We also need to use population models that integrate epidemiology and community ecology. In this context, two main action goals arise: short-term management to reduce disease damage and pathogen spread, and long-term management for species conservation and forest restoration. How to deploy existing tools most efficiently depends on which goal applies, on the spatial scale of the outbreak (e.g., stand with single landowner or watershed), and on practical constraints. As observation data on the efficacy of treatments at individual-tree and community levels are still very limited, we use parameterized mathematical models (Cobb et al. 2012, Filipe et al. 2012) that represent the spatial spread of the pathogen, the competing recruitment of tree species, and the changing forest composition in order to assess the efficacy of management strategies at two spatial scales.

## Models Used and Scenarios Explored

### Stand-Scale Management – Conservation of Tanoak

We considered the stand scale, represented by a hypothetical plot with a few hectares and a single landowner. The management goals are 1) to reduce disease in the short term, and 2) to retain the tanoak (*Notholithocarpus densiflorus* (Hook. & Arn.) Manos, Cannon & S.H. Oh) population in the long term. We used a lattice-structured metapopulation model (Cobb et al. 2012) characterized by (fig.1): 1) units (20m) of differing and changing species composition, 2) trees species that have natural death and compete for recruitment, 3) pathogen spread at local scale in bay laurel

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<sup>1</sup> A version of this paper was presented at the Sudden Oak Death Fifth Science Symposium, June 19-22, 2012, Petaluma, California.

<sup>2</sup> Department of Plant Sciences, University of Cambridge, Cambridge, CB2 3EA, UK.

<sup>3</sup> Department of Plant Pathology, University of California at Davis, Davis, CA 95616, USA.

<sup>4</sup> École Normale Supérieure, Paris, France.

Corresponding author: jf263@cam.ac.uk

(*Umbellularia californica* (Hook.& Arn.) Nutt.) and tanoak, and 4) tanoak trees that are killed by the pathogen and can sprout. We added to the model (Cobb et al. 2012) the following management strategies with treatments applied once or twice across the whole stand: 1) removal of bay laurel (curative and pre-emptive), 2) protection of tanoak (preventive, e.g., Agri-Fos<sup>®</sup>), and 3) a mixed/combined strategy.

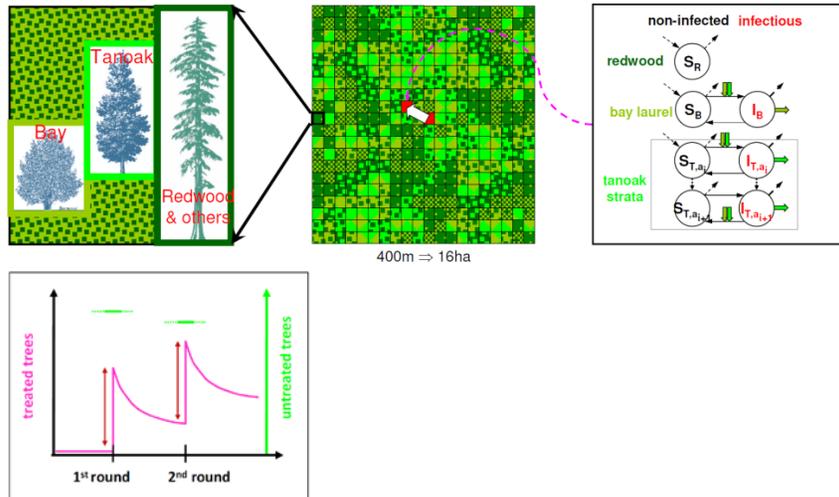


Figure 1—Stand-level epidemiological and ecosystem model, and management schedule.

## Watershed-Scale Management – Restoration of Forest Services

Second, we considered the watershed scale, represented typically by a landscape with tens of km<sup>2</sup> and multiple landowners. We used the Mattole watershed in Humboldt County, California, as an example where a positive sample has been found and there is an opportunity to inform disease management and control. The management goals are 1) to contain the pathogen outbreak in the short term, and 2) to restore forest services in the long term through partial replacement of hosts with conifers. We used a lattice-structured metapopulation model (Filipe et al. 2012) characterized by (fig. 2): 1) units (250 m) of differing but constant species composition (CALVEG dataset), 2) pathogen spread over small and large distances, 3) specific weather conditions, and 4) cryptic infection prior to detection of symptoms (mortality) in aerial surveys. We added the following management strategies to the model (Filipe et al. 2012) with treatments applied annually in a confined zone of the host landscape: 1) detection and removal of hosts in symptomatic and adjacent units (curative and pre-emptive, with partial efficacy) (figs. 4.2-4.4), 2) forest restoration (fig. 4.5) by replacing 50 percent of the hardwood hosts with conifers ahead of the pathogen, and 3) a mixed/combined strategy (fig. 4.5). In this watershed, the outbreak develops in an area 30 km x 35 km since 2011, and management was implemented since 2012.

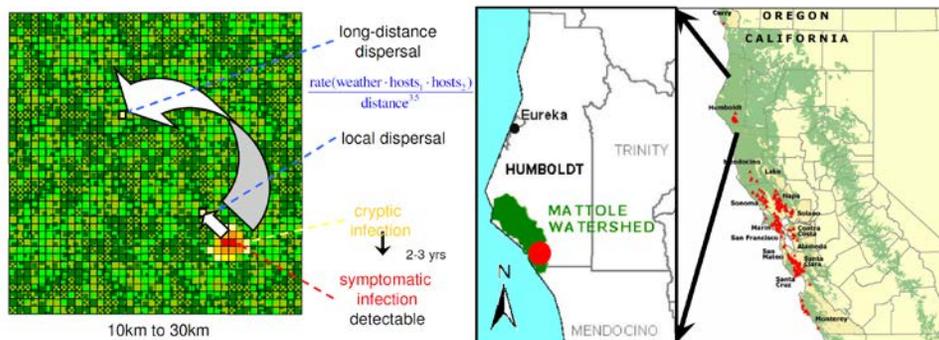


Figure 2—Watershed-level epidemiological model.

## Conclusions

### Stand-Scale Management – Conservation of Tanoak

Disease management that is effective and promotes tanoak conservation (increased durability<sup>5</sup>) requires:

- 1) Long-term follow-up (fig. 3A) and large coverage (percent of population treated) (figs. 3B, 3D).
- 2) Accompanying removal of bay laurel with herbicidal application – adding herbicide improves the durability of tanoak dramatically by preventing stump re-sprouting; alternatively, the application of follow-up treatments is the next best option (fig. 3B).
- 3) Specificity to forest composition (tanoak and bay laurel) prior to pathogen invasion – the extra durability of tanoak due to protective treatments declines rapidly with bay laurel prevalence (fig. 3C).
- 4) Combining preventive and curative treatments – offers the greatest increase in tanoak durability by combining the benefits of each treatment in a given pre-invasion forest composition (fig. 3A, 3D).

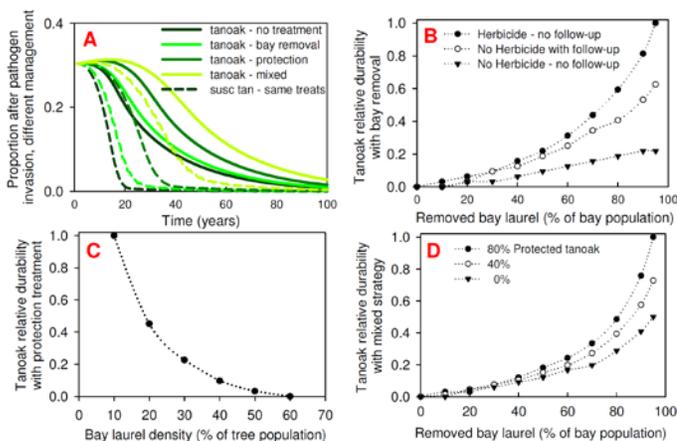


Figure 3—Results from the stand-level epidemiological and ecosystem model.

### Watershed-Scale Management – Restoration of Forest Services

- 1) The mixed strategy, combining curative treatment and partial replacement of hosts with non-host species (fig. 4.1), is the most effective in delaying, and possibly containing, the pathogen.
- 2) The differing payoff of the control scenarios only becomes apparent after several years (figs. 4.2-4.5).

<sup>5</sup> Tanoak relative durability = rescaled time to ½ population decline.

- 3) Forest restoration with non-host species may be a viable long-term, commercially fruitful approach to containing pathogen spread and restoring ecological functions.
- 4) Cryptic infection and long-distance dispersal of generalist pathogens pose very challenging conditions to forest and disease management – it is critical to act early, to treat cryptic infections, and to protect the wide surrounding landscape (figs. 4.4-4.5).
- 5) We are investigating the implications of heterogeneous patterns of landownership and cooperation for the effectiveness of these forest management strategies.

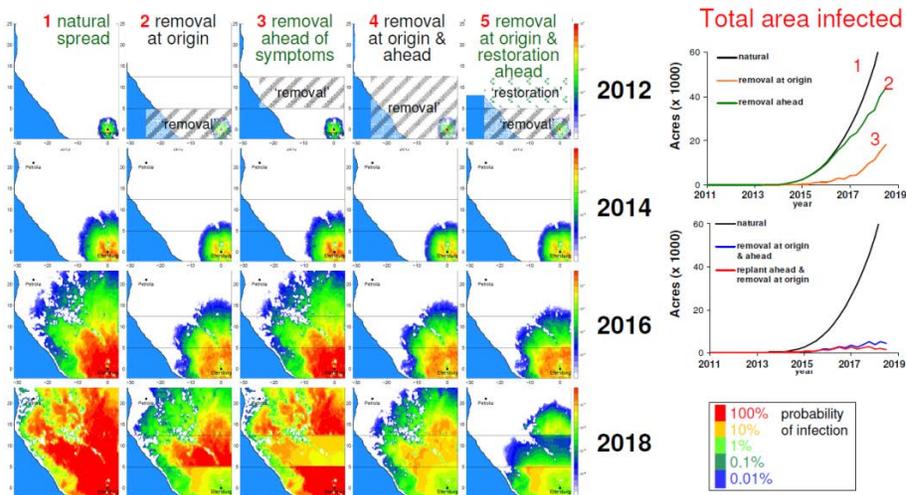


Figure 4—Results from the watershed-level epidemiological model.

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