Research on the Epidemiology, Ecology and Management of *Phytophthora ramorum* in California Forests[1]

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Introduction

The ultimate goal of *Phytophthora ramorum* research is to develop disease management strategies. To date, studies have been focused at three management levels: the individual tree, the landscape (or forest stand), and the regional to international scale (Garbelotto and others 2003, Rizzo and Garbelotto 2003, Rizzo and others 2005). I will focus my brief remarks on the forest landscape, possibly the most difficult level to implement disease control strategies (for a more comprehensive discussion see Rizzo and others 2005).

From a research perspective, there are four non-exclusive areas that we must continue to focus on in order to facilitate *P. ramorum* management in forest stands:

Put the impacts of sudden oak death in context with expected successional patterns and ecosystem processes within coastal forests

For any *P. ramorum* management proposal to be successful in coastal California forests it must also be put into context with other management goals (e.g. timber extraction, wildlife) and threats (e.g., high fuel loads due to fire suppression, other invasive species) (Rizzo and others 2005). This requires continued study on the ecology of the invaded forests in addition to examining the biology of *P. ramorum*. This pathogen has invaded three broad forest types in California: mixed-evergreen forests dominated by coast live oak (*Quercus agrifolia*), mixed-evergreen forests dominated by tanoak (*Lithocarpus densiflorus*) and Douglas-fir (*Pseudotsuga menziesii*), and coast redwood *(Sequoia sempervirens*) forests. With the possible exception of the coast redwood forest type, the ecology of many coastal mixed-evergreen forests has not been well characterized (Barbour and Minnich 2000). Knowledge of the dynamics of coastal forests will allow for

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setting management objectives beyond simply disease management (e.g., Moritz and Odion 2004).

Have a good understanding of host and pathogen biology

For managing any plant disease, the importance of understanding the various components of the disease triangle is obvious, but is well worth reiterating. The establishment and spread of *P. ramorum* across a forest landscape will be dependent on pathogen biology, host susceptibility and environmental conditions. When the connection of *P. ramorum* to sudden oak death was first made in 2000, there was essentially nothing known about the biology of this organism. The finding that *P. ramorum* has a very broad host range allowed us to begin to piece together the life history of the pathogen in the forests. A key discovery was that sporulation of *P. ramorum* primarily occurs on bay laurel (*Umbellularia californica*) in California and it is this host that appears to be the main driver of the epidemic (Davidson and others 2005). After five years there is still much we do not know; numerous research projects presented at this symposium are examining many other aspects of pathogen biology such as survival in soil, infection biology, host range, and mating studies.

Coast live oak and tanoak, the two hosts impacted the most by *P. ramorum*, are not commercial timber trees. Therefore, relatively little is known about the biology of the hosts, in particular the population genetics and how this may fit into disease resistance (Dodd and others 2005). In addition, research has shown variation in susceptibility of bay laurel (Hüberli and others, 2005). At what scale resistance occurs (see below) and how to utilize such information in disease management and forest restoration are key questions that still need answers.

Consider multiple spatial scales

Research on the biology of hosts and pathogens must be taken to larger scales in order to be effectively translated in landscape management protocols. There must also be constant feedback between research at different scales. For example, Swiecki and Bernhardt (2002) were the first to document an association between sudden oak death and the presence of bay laurel at the landscape level; this was several months before bay laurel was determined to be a host based on isolation and inoculation studies. Movement between scales offers the potential to understand mechanisms and explain large scale patterns (e.g., Cushman and others 2005).

Numerous research plots have been established in California coastal forests since 2000 to understand disease progression and ecological impacts at various spatial scales

ranging from individual trees (e.g., McPherson and others, 2005) to the landscape (e.g., Swiecki and Bernhardt 2002, 2005; Maloney and others 2005). GIS has also been utilized from the earliest days of sudden oak death research (e.g., Kelly and Meentemeyer 2002). Using such information, risk models have been developed for California to target areas that are currently without the pathogen, but may be at high risk for invasion (Guo and others 2005, Meentemeyer and others 2004). These models demonstrate the integration of data on host range, transmission biology and plant community structure to develop models of *P. ramorum* establishment and the risk of spread in plant communities. Models must eventually incorporate the effects of spatial and temporal variability of multiple environmental variables on pathogen persistence.

Utilize long term observations and datasets

Many forest disease epidemics have been expressed over long periods of time (e.g., chestnut blight, white pine blister rust) (Smith 1996.). Focusing on short periods of time can give a false sense of the biology of an organism and its impacts in forest ecosystems. For example, we have been examining sporulation patterns of *P. ramorum* in coastal California forests for nearly five years (Davidson and others 2002, 2005; P. Maloney, unpublished data). Yearly variation in rainfall patterns and temperature influences sporulation patterns of *P. ramorum* (Davidson and others 2005). Late rains in spring 2003 resulted in a twenty fold increase in sporangial production, as collected in rainwater, over the previous two springs in a mixed- evergreen forest (Davidson and others 2005). Similar findings occurred in spring of 2005 (Davidson, unpublished data). Such data point to the potential importance of longer term climatic events, such as El Niño, in influencing the establishment and spread of *P. ramorum*.

There are many threats to California coastal forests (Barbour and others 1993); the damage caused by *P. ramorum* is just one of them. Through the development of collaborations between researchers (including plant pathologists, ecologists, entomologists, wildlife biologists, etc.) and managers, we can begin to integrate disease management into a broader landscape view. Much has been accomplished in *P. ramorum* research over the past five years, but there is still a ways to go.

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