Managing Emerging Forest Disease Under Uncertainty

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1. Summary

I will use epidemiological and economic models to determine best approaches to managing and conserving forests in the face of emerging forest disease, a force of environmental change that is rapidly transforming forests. My results will be applicable in decision-making related to Sudden Oak Death in California, and provide insight into general problems where threshold effects drive disease dynamics, especially where knowledge of these thresholds is uncertain.

2. Background

Forest diseases can radically transform ecosystems. In North America, chestnut blight, Dutch elm disease and beech bark disease have caused precipitous declines in their hosts, leading to changes in the structure and function of forests. Changes from such diseases may be the dominant force changing the face of forests in coming decades, overwhelming other forms of rapid environmental change such as climate change (Lovett et al. 2006).

Sudden Oak Death (SOD) is an emerging forest disease in California and Oregon that poses risks to forest across North America. First observed in California in the mid-1990s, SOD is caused by the water mould *Phytophthora ramorum* (Rizzo et al. 2002a). *P. ramorium* often kills tanoak (*Notholithocarpus densiflorus*), which provide habitat and food to many vertebrate species, and are the primary host of ectomycorrhizal fungi in redwood forests (Rizzo and Garbelotto 2003). Loss of this species may have cascading effects on other species. The disease has also caused significant economic damage through removal costs and property value reduction (Kovacs et al. 2011). It has the potential to spread to species in other regions, such as northern red oak (*Quercus rubra*), one of the most important eastern timber species (Rizzo et al. 2002b).

Much recent work has focused on predicting and managing the spread of SOD (Meentemeyer et al. 2011, Filipe et al. 2012). Yet in many areas, SOD is already so well established that eradication is infeasible. Landowners thus need strategies to manage forest and conserve species under an ever-present risk of disease.

The dynamics of SOD are highly dependent on forest community composition, which changes as forests age. This is because *P. ramorum* has a wide host range, yet its lethality and transmissivity vary greatly by host. For instance, while it most often kills tanoak, it produces many more spores in California bay laurel (*Umbellularia californica*), which suffers no ill effects (DiLeo et al. 2009). It has intermediate effects on many other species. Lethality also varies considerably with tree size (Cobb et al. 2012), and both lethality and transmissivity vary between individuals of the same species (Rizzo and Garbelotto 2003). Epidemiological modeling (Cobb et al. 2012) indicates that the disease has a host-density threshold. Below a critical concentration of host trees, the disease and hosts remain in a stable equilibrium. Above the threshold, increased transmission leads to disease outbreak and host decline. This dynamic could be exploited to maintain the disease at manageable levels.

While the host-density relationship is qualitatively robust, and has been observed in other disease and parasite systems (Davis et al. 2004, Frazer et al. 2012), actual threshold levels for SOD are uncertain. The relative novelty of the disease, its broad host range, and considerable variation in individual and community properties mean that thresholds will be difficult to predict at small scales, such as the scale of an individual land parcel that must be managed. Also, *P. ramorum* infection requires considerable effort to detect - some species may show no signs of infection at early stages, and it is cost-prohibitive to examine every leaf. This limits the ability to estimate stand-level infection and manage forests appropriately. General techniques for estimating ecological thresholds are being developed (Scheffer et al. 2001, Carpenter et al. 2011), but they are limited in statistical power (Boettiger and Hastings 2012), and only work under a limited set of theoretical conditions (Hastings and Wysham 2010).

Management techniques for SOD must be robust to such uncertain thresholds. Such approaches are applicable to managing many diseases, pests and parasites, as new outbreaks must be managed even as details of the threat are unknown. This is a challenging economic problem that has not been studied in the context of forest management. Polasky et al. (2011) showed that, when managing natural resources subject to threshold-driven changes in dynamics, the optimal approach is to exercise precaution by reduce pressure. However, in this case the probability of regime shift was a known quantity. Brozović and Schlenker (2011) explored how optimal decisions change with uncertainty, but only under equilibrium conditions, not under a dynamic regime such as forest growth and management. Also, neither of these cases have examined optimal behavior when the natural resource primarily provides continuous ecosystem services, rather than timber harvest value, as is the case with tanoak. Previous work on managing forest diseases has focused on optimal balance between detection and control efforts (Bogich et al. 2008, Ndeffo Mbah and Gilligan 2010), and slowing spread vs. eradication strategies (Sharov and Leibhold 1998). These efforts have focused on landscape-level decisions, but not those faced at the scale of individual landowners.

3. Goal

My research will try to determine **What is the best way to manage forests at risk from emerging disease outbreaks?** Using a combination of epidemiological and economic modeling approaches, I will address these specific questions:

- How does the risk of disease affect optimal management under dual goals of species conservation and timber harvest?
- How should one allocate resources between preventative measures that reducw risk of disease entering the property, and removing trees to prevent the disease from reaching outbreak levels?
- How does the optimal strategy change with the level of uncertainty of disease outbreak?
- How does does the optimal strategy change if uncertainty decreases over time, as when more is learned about the biology of a new disease?

4. Methods

Developing a local community-epidemiolgical model

SOD epidemiology has been modeled at a range of scales and complexities, from simple stylized forms (Ndeffo Mbah and Gilligan 2010) to stochastic, spatially explicit, landscape-scale, computationally intense models designed for forecasting (Meentemeyer et al. 2011, Filipe et al. 2012). Building on these efforts, I will develop a model that represents the essential growth and disease dynamics that are important for decision-making at the forest stand scale. The model will (a) include local stand-level growth and turnover dynamics of multiple species (b) include disease transmission and mortality, and (c) be subject to external forcings, such as weather and regional disease spread that modify disease risk. Importantly, it will explicitly represent stochasticity in disease dynamics and uncertainty in disease detection.

In order to produce robust analytical results I may produce both a "full-form" model and a "reduced-form" model that reproduces essential threshold dynamics in a more simplistic framework. I will thus produce analytical results from the "reduced-form" model and confirm results numerically with the "full-form" model.

Dynamic economic optimization

Using the model developed above I will derive optimal control strategies for forest management under the threat of disease outbreak. The basis of this work will be the Hartman (1976) economic modeling framework, in which forest owners are motivated by dual goals of continuous ecosystem service amenities and profit from timber harvest. Under this framework, the optimal control will minimize the costs associated with quarantine and equipment cleaning, while maximizing both the standing biomass of valued species and their timber value. Both time discounting and risk-aversion will be included in the maximization scheme.

5. Interdisciplinary Approach and Qualifications

This study requires integrating methods for empirical plant pathology, forestry, theoretical ecology and natural resource economics. Successfully translating the natural history of the study organism and system require knowledge of plant pathology, while theoretical ecology provides the foundation for epidemiological modeling, and economics provides the tools for optimization. I have a unique ability to work across these fields - my training is in theoretical biology and forestry, and I have pursued coursework in economics. In my previous career as a management consultant, and as a REACH IGERT trainee, I have worked across multiple disciplines and institutions to ecological science to address management problems. This work emerged from a seminar I organized in Fall 2011 bringing together empirical entomologists and pathologists with ecological theorists and economists to explore problems related to pest and disease outbreaks and forests.

My supervisors, David Rizzo and Jim Sanchirico, provide complementary expertise to support this research. Rizzo, a plant pathologist, has extensive knowledge of *P. ramorum* and its ecology, as well as years of experience working with the U.S. Forest Service and other agencies in managing the disease. Through his contacts I will be able to gather relevant cost data, as well as the opportunity to present results to an audience that will have practical feedback and immediate use for my work. Jim Sanchirico provides expertise in natural resource economics in both theoretical and applied settings. In addition, my advisor Alan Hastings provides expertise in theoretical ecology and epidemiology.

This interdisciplinary research will have immediate applications in managing Sudden Oak Death, an emerging but fast-paced threat to U.S. forests, and provide tools for dealing with many problems in environmental change with uncertain thresholds.

6. References

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