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Spatial Modeling of the Mountain Pine Beetle Attack Process

Barbara Bentz[1], Jim Powell[2], and Jesse Logan[1]
[1]USDA Forest Service, Rocky Mountain Research Station, Logan, UT
[2]Department of Mathematics and Statistics, Utah State University, Logan, UT

Spatial dynamics play a central role in the community dynamics of highly mobile insects. For example, dispersal is one of the most important, yet least understood, factors of bark beetle population biology. Past research with the mountain pine beetle (MPB) indicates that spatial dynamics play a crucial role (Preisler and Mitchell 1993; Mitchell and Preisler 1991, Safranyik et al. 1992). The MPB has long been considered a major pest of western forests. As an aggressive bark beetle (one that kills its host) eruptions of this species are impressive events. Outbreaks can be both intensive (up to 80% or greater mortality) and extensive (covering thousands of contiguous acres), resulting in serious economic consequences. It is also becoming recognized that disturbances, such as MPB outbreaks, may be central to maintaining the structure, function, and health of western forests. Interpretation of the mountain pine beetle in this dual role as a serious economic competitor and as a co-evolved component of the ecosystem presents an interesting challenge. One important method we are incorporating to help address this challenge is development and analysis of quantitative models. Aggregation on and dispersal from a host are of such over-riding importance to MPB ecology that including spatial dynamics in model representations is essential for ecological credibility. The spatial self-focusing and self-dissipating aspects of this species chemical ecology are integral components affecting population spatial dynamics.

Over the past 6 years we have been developing a reaction-diffusion partial differential equation (PDE) model of the spatial interaction between the mountain pine beetle and its host trees, including critical components of the species chemical ecology (Logan et al. 1998; Powell et al. 1996; Powell et al. 1998; Powell et al. 2000). We are working on both the large, landscape-level scale, and the smaller, stand-level scale. From these modeling endeavors, we have observed that even starting with a completely homogenous environment, the positive and negative feedback generated by attacking beetles soon results in a rich, spatially dependent chemical landscape that tends to modify future events.

The large-scale mountain pine beetle redistribution process, as described by the nonlinear reaction-diffusion PDE, has proven to be remarkably descriptive of published observations of the behavior of attacking MPB populations. We were able to parameterize the small-scale model using field collected data from an infested MPB stand in central Idaho (Bentz et al. 1996; Beisinger et al. 2000). Included in this is the important switching behavior of MPB from a focus tree to other nearby trees (Powell et al. 1998). Our field results indicate that verbenone does not appear to act as a 'shield' around attacked trees, and is therefore not solely responsible for the switch of beetle attacks to a new tree. We evaluated our model of switching with respect to changes in the value of several parameters: 1) vigor of the secondary tree, 2) distance between the focus and secondary tree, 3) strength of background emergence, and 4) the rate of pheromone loss through the canopy. All four factors play an important role in the successful colonization of hosts in an area. Results from the model indicate that control measures based on stand thinning are probably successful, at least in part, because of interference with the MPB chemical communication. In most cases the boundary within which switching is likely to be successful was relatively insensitive to host vigor. Conversely, the boundary's spatial location was very sensitive to chemical loss rate through the canopy, which is the parameter most strongly reflecting stand density in this model. Consequently, this work suggests that interference with chemical communication among beetles is a critical component of stand thinning.

Our modeling endeavors have provided a convincing tool for analyzing MPB movement within a stand and across a landscape. From this we have been able to test researchable hypothesis. We are moving in the direction of using our models to include the spatial component of MPB populations into risk assessment tools for this important forest insect.

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