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A Dynamical Model for Bark Beetle Outbreaks

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Abstract

Tree-killing bark beetles are major disturbance agents affecting coniferous forest ecosystems. The role of environmental conditions on driving beetle outbreaks is becoming increasingly important as global climatic change alters environmental factors, such as drought stress, that, in turn, govern tree resistance. Furthermore, dynamics between beetles and trees are highly nonlinear, due to complex aggregation behaviors exhibited by beetles attacking trees. Models have a role to play in helping unravel the effects of variable tree resistance and beetle aggregation on bark beetle outbreaks. In this article we develop a new mathematical model for bark beetle outbreaks using an analogy with epidemiological models. Because the model operates on several distinct time scales, singular perturbation methods are used to simplify the model. The result is a dynamical system that tracks populations of uninfested and infested trees. A limiting case of the model is a discontinuous function of state variables, leading to solutions in the Filippov sense. The model assumes an extensive seed-bank so that tree recruitment is possible even if trees go extinct. Two scenarios are considered for immigration of new beetles. The first is a single tree stand with beetles immigrating from outside while the second considers two forest stands with beetle dispersal between them. For the seed-bank driven recruitment rate, when beetle immigration is low, the forest stand recovers to a beetle-free state. At high beetle immigration rates beetle populations approach an endemic equilibrium state. At intermediate immigration rates, the model predicts bistability as the forest can be in either of the two equilibrium states: a healthy forest, or a forest with an endemic beetle population. The model bistability leads to hysteresis. Interactions between two stands show how a less resistant stand of trees may provide an initial toe-hold for the invasion, which later leads to a regional beetle outbreak in the resistant stand.

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