Linking agent-based models to data using a hierarchical Bayesian framework

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Agent-based models (ABMs) have enabled researchers to simulate details of complex systems, including interactions between individuals, environmental stochasticity and spatial hierarchies. The flexibility of the ABM approach also presents the opportunity to link submodels for processes in ABMs to statistical models parameterized with real data. By directly linking ABMs to data, researchers can present realistic estimates of model uncertainty, design better sampling strategies for future data collection and analyze how parameter variability contributes to output variability. In this paper, we used hierarchical Bayesian statistical models to link field data and an ABM simulating spatial population dynamics of a tropical tree species. A major knowledge gap in forest ecology is understanding how spatial processes, including seed dispersal and competitive interactions between individuals, shape population dynamics throughout the complex life cycle of trees, including multiple stages (seeds, seedlings and adults) and sizes. We parameterized statistical models for tree survival, growth and reproduction using a combination of experimental and long-term census data from a tree population in western Thailand. Our Bayesian statistical framework enabled us to propagate uncertainty in parameter estimation into ABM output, using draws from the posterior distribution of each parameter as input to different ABM runs. We then conducted a global sensitivity analysis using the probability density of parameter samples and ABM output, enabling us to quantify the sensitivity of ABM output to perturbations in parameters. Our results demonstrate the crucial importance of seed dispersal and spatial competition for tree populations and provide an example of how linking ABMs to data can improve our understanding of agent-based models.