Comparison of Agent-Based, Mean Field, and Pairwise Models of a Predator-Prey Ecosystem

Mohamed Coulibaly, István Balázs
University of Szeged, Szeged, Hungary

Stochasticity and spatial structure significantly influence predator-prey dynamics yet are often overlooked in traditional mean-field models. We conduct a comprehensive comparison of three modeling methodologies for a spatial predator-prey system: Monte-Carlo simulations of stochastic agent-based systems, deterministic mean-field, and pairwise approximation.
We implement an agent-based model in which sheeps (preys) and wolves (predators) experience stochastic movement, reproduction, and mortality.
We use this agent-based framework to systematically derive the relevant mean-field equations assuming spatial homogeneity, as well as the pairwise model that incorporates nearest-neighbor correlations via moment closure approximations. We analyze the three techniques under different parameter regimes, extinction events, and oscillatory dynamics [1], [2].
Our results show that, while the mean field approximation qualitatively represents coexistence regimes, it fails to accurately recreate stochastic extinction processes. For certain parameter combinations, the pairwise model improves agreement with agent-based Monte Carlo simulations by accounting for local correlation effects, although discrepancies remain in substantially fluctuation-dominated regimes.

[1] R. M. May, Limit cycles in predator-prey communities, *Science* **177** (4052), 900–902 (1972).

[2] I. Z. Kiss, J. C. Miller, P. L. Simon, *Mathematics of epidemics on networks: from exact to approximate models*, Interdisciplinary Applied Mathematics, Vol. 46, Springer, Cham, 2017.