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Species coexistence in the face of uncertainty

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A long standing, fundamental question in biology is "what are the minimal conditions to ensure the long-term persistence of a population, or to ensure the long-term coexistence of interacting species?" The answers to this question are essential for identifying mechanisms that maintain biodiversity and guiding conservation efforts. Mathematical models play an important role in identifying potential mechanisms and, when coupled with empirical work, can determine whether or not a given mechanism is operating in a specific population or community. For over a century, nonlinear difference and differential equations have been used to identify mechanisms for population persistence and species coexistence. These models, however, fail to account for intrinsic and extrinsic random fluctuations experienced by all populations. In this talk, I discuss recent mathematical results about persistence and coexistence for models accounting for demographic and environmental stochasticity.

Demographic stochasticity stems from populations consisting of a finite number of interacting individuals. These dynamics can be represented by Markov chains on a countable state space. For closed populations in a bounded world, extinction in these models occurs in finite time, but may be preceded by long-term transients. Quasi-stationary distributions (QSDs) of these Markov chains characterize this meta-stable behavior. These QSDs correspond to an eigenvector of the transition operator restricted to non-extinction states, and the associated eigenvalue determines the mean time to extinction when the Markov chain is in the quasi-stationary state. I will discuss under what conditions (i) this mean time to extinction increases exponentially with "habitat size" and (ii) the QSDs concentrate on attractors of the mean field model of the Markov chain. These results will be illustrated with models of competing Californian annual plants and chaotic beetles.

On the other hand, environmental stochasticity stems from fluctuations in environmental conditions which influence survival, growth, and reproduction. These effects on population and community dynamics can be modeled by stochastic difference or differential equations. For these models, "stochastic persistence" corresponds to the weak* limit points of the empirical measures of the process placing arbitrarily little weight on arbitrarily low population densities. I will discuss sufficient and necessary conditions for stochastic persistence. These conditions involve Lyapunov exponents corresponding to the "realized" per-capita growth rates of species with respect to stationary distributions supporting subsets of species. These results will be illustrated with models of Bay checkerspot butterflies and competing perennials in space-limited environments.