

Dr. Thomas Caraco
Department of Biology

Sponsor: National Science Foundation
Amount: \$148,295
Dates: July 15, 2009 – June 30, 2012

**“Collaborative Research: QEIB: Spatial Ecologies Under
Temporal Variation”**

Intellectual Merit

Spatially structured biotic interactions generate demographic variation at the level of individuals; this variation can govern ecological invasion and competitive coexistence. Temporal abiotic variation can directly modulate demographic rates, exerting further effects on competitors' dynamics. Theory for individual-based spatial processes has remained distinct from theory for population dynamics in temporally variable environments. Therefore, we propose to study the interplay between discrete, stochastic spatial interactions and temporally varying environmental forces, with a focus on competitive invasion. To advance understanding of the multi-scale ecological complexity predicted by the theory, and to identify novel predictions, we apply concepts of statistical physics.

To motivate the interdisciplinary collaboration (one PI in ecology at SUNY Albany, the other in statistical physics at Rensselaer), we summarize prior results on a superior competitor's invasion of an inferior resident species in a constant environment. When introduction occurs only rarely, spatial competition will be driven by local dispersal and mortality, so that we can apply the physical theory for nucleation of spatial systems. Low introduction rates and small environments may permit only single-cluster invasion by the superior competitor. Increasing the introduction rate or system size allows multi-cluster invasive growth. In both regimes, the invasion dynamics exhibits strong spatial correlation and stochasticity. Consequently, standard deterministic approaches fail to predict the behavior of the invasion process. However, for multi-cluster invasion, the time to competitive exclusion is approximated accurately by Avrami's law, an analytical framework of nucleation theory. The Avrami result links individual-level propagation and mortality rates to community-level features of spatial invasion, a major research objective in ecology. The most general research objective we propose is developing an integrative theory of stochastic spatial growth; judicious parameter choice should let the theory address data on invasive fronts ranging from the within-habitat to the biogeographic scale. To study invasion in two-dimensional environments, we analyze stochastic “roughening” of advancing fronts; several results apply to a broad class of spatial-growth models. Analysis has yielded novel predictions; habitat size (length of the front) should affect both invasion velocity and the expected location of the maximal invasive incursion beyond the front's mean position.

The proposal describes a field experiment designed to test these hypotheses with clover-ryegrass fronts of different lengths. Specific research objectives include understanding the interactive effects of preemptive and interference competition on the cluster dynamics of invasive growth, and investigating the impact of some longer-distance dispersal (relaxation of diffusion limitation) on the dynamics of two-dimensional stochastic fronts. Most importantly, we propose new theory for spatial competition in a time-varying environment. If each species is alternately favored, single-cluster invasion may admit competitive coexistence via stochastic resonance, indicating a matching of the (stochastic) spatial-dynamic and (periodic) environmental time scales. The multi-cluster mode may exhibit different limit cycles and long-term coexistence through large-scale clustering of each species, depending on comparison of the population dynamics' characteristic time scale and the period-length of environmental variation.

Following QEIB guidelines, the research develops new approaches to understanding stochastic, nonlinear effects in ecological systems. The research will lead to insights concerning the way individual-based ecological interactions may amplify or attenuate environmental variability.

Broader Impacts

The PIs put special emphasis on the education and training of young scientists at both graduate and undergraduate levels at SUNY Albany and at Rensselaer. The PIs are developing two new courses, one designed to enhance quantitative skills of ecology students, and a second to introduce contemporary challenges in ecological research to students from physics and mathematics. Broader dissemination will be done through the web and through outreach to science-oriented local high-school students.