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Movement toward better environments and the evolution of rapid diffusion ☆

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Abstract

We study a reaction–diffusion–advection model for two ecologically equivalent competitors with different dispersal strategies inhabiting a spatially heterogeneous environment. The competitors represent different phenotypes of the same species. One is assumed to disperse by simple diffusion, the other by diffusion together with directed movement toward more favorable environments. We show that under suitable conditions on the underlying spatial domain, the competitor that moves toward more favorable environments may have a competitive advantage even if it diffuses more rapidly than the other competitor. This is in contrast with the case in which both competitors disperse by pure diffusion, where the competitor that diffuses more slowly always has the advantage. We determine competitive advantage by examining the invasibility, i.e. stability or instability, of steady states with only one competitor present. The mathematical approach is a perturbation analysis of principal eigenvalues.

Keywords: Reaction–diffusion–advection; Competition; Lotka–Volterra; Evolution of dispersal; Heterogeneous environments; Principal eigenvalues; Eigenvalue perturbation

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1. Introduction

The effects of dispersal on population dynamics, ecology, and evolution have been widely studied from a variety of viewpoints; see for example [1–7] and the references cited in those works. A natural question about dispersal is to determine which patterns of dispersal can be expected to confer some sort of selective or ecological advantage. This question has been examined by a number of investigators using various modeling approaches, including but certainly not limited to McPeek and Holt [2], Belgacem and Cosner [8], Holt and McPeek [4], Dockery et al. [5], Hutson et al. [6] and Cosner and Lou [9]. An important distinction is made by McPeek and Holt [2] between unconditional dispersal, which does not depend on habitat quality or population density, and conditional dispersal, which does depend on such factors. Passive diffusion, as considered by Dockery et al. [5] and Hutson et al. [6], is a type of unconditional dispersal. Diffusion combined with directed movement upward along resource gradients, as considered by Belgacem and Cosner [8] and Cosner and Lou [9], is an example of conditional dispersal, because the bias in the direction of dispersal depends on the spatial distribution of resources. There is evidence based on modeling that for unconditional dispersal in spatially varying but temporally constant environments slower dispersal rates can confer a selective advantage. This was shown in the context of a simple two-patch discrete time model by McPeek and Holt [2] and in the context of diffusion models by Dockery et al. [5]. However, for unconditional dispersal in environments that vary both in space and over time faster dispersal rates may be advantageous in both simple two-patch models [2] and diffusion models [6]. McPeek and Holt [2] also showed that in spatially variable but temporally constant environments certain types of conditional dispersal can confer a selective advantage, again in the context of simple two-patch models. In diffusion–advection models for a single population in a spatially varying but temporally constant environment, Belgacem and Cosner [8] and Cosner and Lou [9] showed that conditional dispersal involving both diffusion and directed movement up resource gradients can sometimes (but not always!) make persistence more likely. The purpose of the present article is to study that type of conditional dispersal in context of competition between two populations that are ecologically identical except in their dispersal mechanisms. This approach is very similar to that taken by Hutson et al. [6], and somewhat similar to but simpler than the approach taken by Dockery et al. [5]. The idea is to think of the competitors as representing different phenotypes of the same species which differ only in their dispersal behavior and to ask which type of dispersal behavior confers a competitive, and thus presumably selective, advantage.

The specific modeling approach we take is to begin with a diffusive Lotka–Volterra model for two identical competitors in a closed but spatially varying environment and then perturb the model by changing the diffusion rate for one competitor while simultaneously changing the diffusion rate and introducing advection up resource gradients for the other. The modeling of movement toward more favorable habitats by introducing an advection term was done *ad hoc* in [8,9] but can be derived from a mechanistic analysis of individual movement via transport equations; see [10]. We assess whether or not this confers an advantage for either competitor by examining the invasibility of states where only one competitor is present by the other competitor. Mathematically, such states will be invasible if they are unstable but will not be invasible if they are stable. If the first competitor can invade when the second is at equilibrium but the second competitor cannot invade when the first is at equilibrium then the first competitor has an advantage in