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A spatially structured metapopulation model with patch dynamics

Dashun Xu[a], Zhilan Feng[a,*], Linda J.S. Allen[b], Robert K. Swihart[c]

[a]Department of Mathematics, Purdue University, West Lafayette, IN 47907, USA
[b]Department of Mathematics and Statistics, Texas Tech University, Lubbock, TX 79409, USA
[c]Department of Forestry and Natural Resources, Purdue University, West Lafayette, IN 47907, USA

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Abstract

Metapopulation models that incorporate both spatial and temporal structure are studied in this paper. The existence and stability of equilibria are provided, and an extinction threshold condition is derived which depends on patch dynamics (patch destruction and creation) and metapopulation dynamics (patch colonization and extinction). These results refine threshold conditions given by previous metapopulation models. By comparing landscapes with different spatial heterogeneities with respect to weighted long-term patch occupancies, we conclude that the pattern of a landscape is of overwhelming importance in determining metapopulation persistence and patch occupancy. We show that the same conclusion holds when a rescue effect is considered. We also derive a stochastic differential equations (SDE) model of the Itô type based on our deterministic model. Our simulations reveal good agreement between the deterministic model and the SDE model.

Keywords: Metapopulation models; Patch dynamics; Spatially realistic models; Fragmentation; Persistence

1. Introduction

When studying populations for which local interactions are relevant, the spatial components of the system are at least as important as average birth and death rates, competition, or predation (Hanski, 1998). Destruction and fragmentation of native habitats are widespread and viewed as the most important threats to biodiversity worldwide (Wilcox and Murphy, 1985). Agriculture, urban sprawl, deforestation, and other human activities change the composition and physiognomy of landscapes, often altering individual behavior (Sheperd and Swihart, 1995; Zollner, 2000), population dynamics (Hanski, 1998), genetic structure (Gaines and Lyons, 1997), and community composition (Wright et al., 1998) of organisms. Thus, the notion of spatially structured populations is increasingly relevant for many species, heightening the importance of spatial ecology in recent years.

From a conservation perspective, there is considerable interest in predicting the sensitivity of species to land-use change and habitat fragmentation as a function of a general suite of ecological (Ims et al., 1993) or behavioral (Laurance, 1995; Wolff, 1999) characteristics. The classic metapopulation model (Levins, 1969) emphasizes changes in patch occupancy as a function of rates of patch colonization and extinction processes. Hanski (1994) proposed using a generalized incidence function model to describe patch colonization and extinction dynamics as functions of patch area and isolation. Hanski and Ovaskainen (2000) and Frank and Wissel (1998, 2002) defined an index of metapopulation capacity for a landscape containing patches that varied in size and connectivity.

Real landscapes exhibit three characteristics not incorporated in most metapopulation models. First, real landscapes are not static; temporal changes in habitat patches occur (e.g. logging or vegetative succession can alter forest patches) and can have important effects on metapopulation persistence (Gu et al., 2002). Disturbance regimes, such as the distribution of anomalous weather events, often drive

*Corresponding author: Tel.: +1 765 494 1901; fax: +1 765 494 0548
E-mail address: zfeng@math.purdue.edu (Z. Feng).

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