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Animal dispersal modelling: Handling landscape features and related animal choices

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Abstract

Animal dispersal in a fragmented landscape depends on the complex interaction between landscape structure and animal behavior. To better understand how individuals disperse, it is important to explicitly represent the properties of organisms and the landscape in which they move. A common approach to modelling dispersal includes representing the landscape as a grid of equal sized cells and then simulating individual movement as a correlated random walk. This approach uses a priori scale of resolution, which limits the representation of all landscape features and how different dispersal abilities are modelled.

We develop a vector-based landscape model coupled with an object-oriented model for animal dispersal. In this spatially explicit dispersal model, landscape features are defined based on their geographic and thematic properties and dispersal is modelled through consideration of an organism's behavior, movement rules and searching strategies (such as visual cues). We present the model's underlying concepts, its ability to adequately represent landscape features and provide simulation of dispersal according to different dispersal abilities. We demonstrate the potential of the model by simulating two virtual species in a real Swiss landscape. This illustrates the model's ability to simulate complex dispersal processes and provides information about dispersal such as colonization probability and spatial distribution of the organism's path.

Keywords: Landscape model; Animal movement; Dispersal behavior modelling; Landscape feature; Object-oriented design; Spatially explicit model

1. Introduction

Understanding how animals disperse is a major issue for the management and conservation of fragmented populations. Landscape heterogeneity and fragmentation affects how organisms are distributed in the landscape (Fahrig and Merriam, 1985; Turner, 1989; Kennedy and Gray, 1997). It determines the

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chance of a patch being colonized (Henein and Merriam, 1990; Hansson, 1991; Taylor et al., 1993; Hanski, 1999; Hanski and Ovaskainen, 2000), can reduce inbreeding in small populations and maintains evolutionary potential (Barton, 1992; Driscoll, 1998; Couvet, 2002). To understand dispersal, it is important to not only consider the dispersal capabilities of the organism but also the complex interaction between the organism's behavior and landscape pattern and use. This is widely recognized in the ecological literature but seldom considered explicitly (Reed and Dobson, 1993; Curio, 1996; Lima and Zollner, 1996; Ulfstrand, 1996; Sutherland, 1998; Caro, 1999; Reed, 1999; Anthony and Blumstein, 2000).

Modelling of animal dispersal provides a useful paradigm for investigating these complex interactions and is seen as an essential conceptual tool for landscape conservation planning (Kareiva and Wennergren, 1995; King and With, 2002; Kramer-Schadt et al., 2004). Due to the difficulty in gathering and interpreting experimental results on animal dispersal processes, simulation models have become a cost-effective approach to understanding dispersal dynamics (Koenig et al., 1996; Tischendorf, 1997; Wiegand et al., 1999; Pretsler et al., 2000; Tischendorf and Fahrig, 2000; Brillinger et al., 2002). Simulation models with spatially explicit landscapes enable the integration of the relationships between species and the landscape and provide representation of the spatial elements that promote or constrain dispersal. Several dispersal models with spatially explicit landscapes have been developed. Some consider dispersal behavior according to habitat affinity or physiological states in order to assess animal movements or provide guidelines for landscape and wildlife management (With and Crist, 1995; Gustafson and Gardner, 1996; Lindenmayer and Possingham, 1996; Blackwell, 1997; With et al., 1997, 1999; Farnsworth and Beecham, 1999; Thulke et al., 1999; Bergman et al., 2000; Wu et al., 2000; Gardner and Gustafson, 2004).

At present, two main kinds of landscape models grid and patch, are used to model spatially structured populations in a continuous landscape (Hanski and Simberloff, 1997; Bian, 2003). These models are characterized by two types of data structures: grid-based and vector-based data structures. Network-based models (Zollner and Lima, 1999b; Conradt et al., 2003) are another approach to modelling landscape with particular emphasis to modelling suitable habitat. We do not consider these models in this paper, as they do not have a continuous representation of the landscape.

1.1. Grid-based models

In dispersal modelling the spatial representation of a landscape is commonly based on grid models where the landscape is represented by a finite number of equally sized cells (Burrough and McDonnell, 1998; With and Crist, 1995; With et al., 1997; Beecham and Farnsworth, 1998; Tischendorf et al., 1998; Carter and Finn, 1999; Thulke et al., 1999; Bergman et al., 2000; Wissel, 2000; Gardner and Gustafson, 2004). These cells can be squares, triangles, hexagons or any other shape that can be used to tessellate the 2D plane. Each cell contains one or more values, which represent attributes of the landscape such as vegetation types, elevation, and temperature. Discretizing the landscape in this way enables flexibility in spatial analysis and mathematical modelling (Burrough and McDonnell, 1998). It offers simple and efficient methods for incorporating state transitions based on properties of a cell and its neighboring cells as is used in cellular automaton (With and King, 1997; Thulke et al., 1999; Wissel, 2000; Anderson and Neuhauser, 2002; Chen et al., 2002).

The criticisms of grid-based models cover three main lines of argument: (i) the existence of an a priori fixed scale of resolution, (ii) in some cases attributes of cells will need to be aggregated (usually an average) at the pre-defined scale and (iii) the limitation in representing line features and topology (shape and relationships between distant objects) (Laurini and Thompson, 1992). The resolution of grid-based models requires a trade off between landscape representation and dispersal mechanisms. If a grid-based approach is used to represent narrow linear features like roads and rivers accurately then the grid will need to be at a very fine scale. This fine resolution may not be appropriate for larger landscape features, such as forests, as it may not capture all the properties of the feature. For landscape features represented by multiple grid cells, parameters associated with the entire landscape feature are distributed into fixed resolution cells instead of having one value being assigned to the entire landscape feature. Conversely, with increased cell size, linear and point landscape features cannot be represented with sufficient accuracy. If a large cell is adopted then the cells that contain linear features, such as roads or streams,