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Gene flow model in a forest for Dogwood

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Abstract

The understanding of gene movement in plant species is critical to the management of both plant and animal species reliant on that plant. Pollen is the mechanism by which plants pass their genetic material from one generation to the next. Pollen dispersal studies have focused primarily on purely random diffusion processes, while this may be a good assumption for species pollinated mainly by abiotic means, such as wind, it is most likely an over simplification for species that are pollinated by biotic means, such as insects [**?**].

Correlated random walk (CRW) models are a model of animal movement [**?**] and have been successfully used to explore the movement of animals in varying ecological contexts [**?**]. An agent-based model (ABM) is developed to describe pollen movement via insects as a correlated random walk (CRW). This model is used to explore how insect path lengths and pollen distribution are affected by the varying turning angle and plant density.

1. Introduction

Pollen is the mechanism by which plants pass their genetic material from one plant to the another. Two modes of transporting pollen, from one plant to another, include abiotic (wind dispersal) and biotic (animal dispersal). Understanding the methods by which pollen spreads across the landscape is important for management of both plant and animal species. Understanding the pollination process may allow for optimization of the number of pollinators used for crop pollination, thereby reducing cost to farmers. Additionally, a better understanding of the pollination process can lead to the prevention of cross pollination of genetically modified plant species and non-genetically modified plant species.

Pollen dispersal studies, for both abiotic and biotic pollen dispersal, have focused primarily on purely random diffusion processes, while this may be a good assumption for species pollinated by wind, it is most likely an over simplification for species that are pollinated by animals [**?**]. A purely random diffusion process in two dimensions accurately predicts pollen dispersal at a particular time, but only for a purely random walk [**?**].

Pollen movement via biotic means may not be a purely random process and therefore would not diffuse in a purely random fashion. In fact, there are several examples of pollinating animals that exhibit *trap line* behavior [**?**]. That is, they follow a particular route as they collect pollen. Thus the movement of animals as they carry pollen may follow more direct paths and therefore would not result in a purely random diffusion process [**?**]. Such behaviors result in dispersal that does not mimic a purely random walk. The movement of animals can be described as a correlated random walk (CRW), where the correlation is based on the distribution and magnitude of random turning angles. In this way the previous direction of travel influences the direction of travel for the next step.

A purely random walk can be used to model a purely random diffusion process such as Brownian motion [?]. While a CRW can be used as a general model of animal movement [?] and have been successfully used to explore the movement of animals in varying ecological contexts [?]. CRW models have been used to model the dispersal of bark beetles, Coleoptera: Scolytidae [?], deterministic diffusion [?], and fractional Brownian motion [?].

An agent-based model (ABM) describing pollen movement via animals as a correlated random walk (CRW) is introduced. ABMs consist of agents that interact with each other and their environment. ABMs allow for simulations that consist of a large number of interacting parts that would not be easily constructed otherwise [?]. Agents can represent things such as people, animals, organizations, etc. that interact with each other and their environment. The environment in an ABM can represent things such as a spatial domain, or a network in which the agents are connected to each other [?]. ABMs have been used in modeling racial segregation, supply chain dynamics, and neural networks [?].

Consequences of the CRW and the interaction of animals with plants is examined using computer simulations. Two animals statistics (*average path distance* and *average maximum distance*) and three plant statistics (*average pollination distance*, *average maximum pollination distance*, and *average weighted diversity of fathers*) are presented. Turning angle and plant density are varied and their effects on animals paths and pollen distribution are examined.

It is shown that bias can be introduced by describing animal movement as a purely random walk. That is, there is a significant difference between the model outcomes for a purely random walk as compared to a CRW. Thus, modeling animal mediated pollen dispersal by way of a purely random diffusion process is likely to result in errors in the approximation of the extent of pollen dispersal.

2. Methods

An agent-based correlated random walk model was built using the java based ABM package REPAST[?]. The model assumes continuous space and consists of two interacting agents; *animals* and *plants*. The plants are considered point sources (i.e. radius of a plant is zero) that release pollen to the animals. Animals transport the pollen across the environment, and at each step, j, animals move from one location to the next. As the animal moves about the environment it searches for plants to collect and deposit pollen. The number of plants is determined by $n = \lfloor \omega \cdot A \rfloor$, where ω is the density of plants, and A is the area of the environment.

2.1. Movement

The movement of animals in this model can be described by three stages: (1) *searching* stage - an animal is moving about the environment in search of plants within a radius of r; (2) *movement to plant* stage - an animal has located a plant and moves to the plant; (3) *movement from plant* stage- an animal has visited a plant and moves away from the plant. Movement transitions from the *searching* stage to *movement to a plant* stage to the *movement away from a plant* stage and then back to the *searching* stage and so on. Each one of these stages have particular animal behaviors associated with them.