A diffusion-based model to predict wild bee dispersal and survival in mixed landscapes

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Abstract

The distribution of native bees across a landscape is an important factor for pollination, conservation, and sustaintability. Pollinator distribution data is difficult and expensive to collect directly, so a mathematical model can be used to extrapolate from known local behaviours and predict large scale population behaviour. Here we present a diffusion-based model with intensive and extensive search modes for the movements of native and domestic bees in a landscape consisting of native and agricultural habitats. We investigate how native bees disperse in response to floral resource distribution and density of other bees, either wild or domestic. Exploration of both single day and season long behaviours gives comprehensive understanding of bee dispersal and resource collection. Our results suggest that the lower number of native bees observed in crops pollinated by honeybees may simply be due to the increased competition for floral resource. We also demonstrate the existence of a lower bound for the size of native habitat needed to maintain a bumblebee population servicing an agricultural crop, and investigate the effectiveness of wild bumblebee populations as pollinators of an agricultural crop.

For a single hive of bees, we derive the following model equations:

$$\frac{\partial F(x,t)}{\partial t} = \overbrace{D\nabla^2 F(x,t)}^{\text{diffusion}} + \overbrace{\gamma_1 \Delta N(x,t) S(x,t)}^{\text{conversion to foraging}} - \overbrace{\gamma_2 F(x,t)}^{\text{conversion to scouting}}, \tag{1a}$$

$$\frac{\partial S_r(x,t)}{\partial t} = \overbrace{-(A_r(x)) \cdot \nabla S_r(x,t)}^{\text{advection R and CPF}} - \overbrace{\gamma_1 \Delta N(x,t) S_r(x,t)}^{\text{conversion to foraging}} + \overbrace{\frac{1}{2}\gamma_2 F(x,t)}^{\text{conversion to scouting}}, \tag{1b}$$

$$\frac{\partial S_l(x,t)}{\partial t} = \overbrace{(A_l(x)) \cdot \nabla S_l(x,t)}^{\text{advection L and CPF}} - \overbrace{\gamma_1 \Delta N(x,t) S_l(x,t)}^{\text{conversion to foraging}} + \overbrace{\frac{1}{2}\gamma_2 F(x,t)}^{\text{conversion to scouting}}, \tag{1c}$$

$$S_T(x,t) = S_r(x,t) + S_l(x,t), \tag{1d}$$

where $F(x,t)$ is the density of foraging bees at x at time t, $S_r(x,t)$ and $S_l(x,t)$ are the density of bees scouting right and left, respectively, and $S_T(x,t)$ is the total density of scouting bees. Bees are central place foragers, in that they must regularly return to the hive to unload the pollen and nectar collected in the field. The overall advection velocity is thus given by $A(x) = v - C_i(x)$, where $C_i(x)$ is a restoring function for scouts moving in direction i, that constrains their movement to within a certain radius of the hive. The function $\Delta N(x,t)$ is the change in nectar production rate at position x and time t.

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