Supplementary Material. ODD (overview, design concepts, and details) protocol for the agent-based model of grazing effects on elm seed dispersal

This model description follows the ODD (overview, design concepts, and details) protocol for describing individual-based models [A1]. The model is implemented in NetLogo (version 6.0.1; [A2]).

1. Overview

1.1. Purpose

Seed dispersal is an important stage in plant reproduction. The seed dispersal of elm trees is influenced by grazing, which is one of the most common human-caused disturbances to ecosystems in arid and semiarid lands. Grazing can directly promote elm seed production [A3,A4]. Moreover, grazing can reduce vegetation cover, which regulates seed survival on the ground [A5]. However, the effects of grazing on seed dispersal have not been fully considered. Moreover, the effects of grazing on elm seed dispersal are commonly intertwined with the wind, the main factor regulating seed dispersal [A6–A8].

Thus, the model simulates the effects of wind direction and grazing intensities on seed densities and the spatial distribution of the elm species, a typical temperate vegetation type. It is the only tree species in sparse woodlands in the study area, Horqin Sandy Land. Compared to the existing ecological model, which mainly focuses on wind and other natural factors, in this model, we consider the indirect effects of grazing, i.e., grazing modifies vegetation cover through gnawing and trampling. Grazing leads to changes in vegetation cover, which, in turn, influences seed dispersion on the ground.

1.2. Entities, state variables, and scales

The model has two kinds of entities, i.e., elm seeds (turtles in NetLogo language) and vegetation coverage (patches). The state variables of the entities are listed in Table S1. Each patch represents 1 x 1 m.

Table S1. The state variables of entities

Entity	State variable	Description	Unit or Values
Seeds	Distance-moved	Distance moved in the current step	patches
	Previous-patch	Patch visited in the previous time step	patch coordinates
	Seed dispersal directions	Seed dispersal directions driven by winds	°
	Wind directions	Frequency of wind directions	%
Vegetation coverage	Coverage in patches	Vegetation coverage in each patch	%
	Grazing intensities	Influence of grazing intensities on vegetation coverage	%

1.3. Process overview and scheduling

Seeds move along the eight wind directions. To be precise, a seed goes randomly into each model simulation step. The direction of seed movement follows a uniform distribution, which simulates wind directions in nature (Table S2). On the other hand, the seed densities in patches are regulated by vegetation cover. The vegetation coverage of each patch is randomly established, and its values are in a range of 0—30%. The relationship between seed densities and vegetation coverage follows an experimental equation in the same study area, i.e., seed densities = -0.131* (vegetation coverage)^2 +9.527* vegetation coverage -30.53. Meanwhile, vegetation cover is influenced by grazing intensities. Heavy grazing (HG), moderate grazing (MG), and light grazing (LG) lead to the loss of vegetation cover in proportions of 85.90%, 45.90%, and 23.70%, respectively. The loss of vegetation cover was randomly allocated into the vegetation cover in patches.

2. Design concepts

2.1. Basic principles

Seed movement is regulated by wind and vegetation cover. Wind improves seed movement and vegetation cover hampers seed movement. As the vegetation cover is different in different patches, the seed has a different probability of moving. Therefore, the number of seeds in each patch (seed density) is different. Moreover, seed density appears as a special spatial pattern (the spatial patterns are uniform pattern, random pattern, and cluster pattern). Grazing reduces vegetation coverage and indirectly influences the spatial pattern of seed density.

2.2. Emergence and Objectives

Spatial patterns of seed densities are the main results of this model. The number of seeds per patch, i.e., seed density, is recorded.

2.3. Adaptation, Learning, and Prediction

Seed movement is passive and mainly regulated by wind direction. Seeds are not intelligent entities, like humans; thus, there is no learning and predictions in the model.

2.4. Sensing and Interaction

Seed movement is passive and influenced by wind and vegetation cover, which is also regulated by grazing. Moreover, there is no interaction among seeds, which is consistent with reality.

2.5. Stochasticity, Collectives, and Observation

The vegetation coverage is randomly distributed. A special seed movement direction in a step was randomly selected from 8 wind directions. The probability of wind directions was designed according to their frequency in the study area. We only observed the seed density in each patch.

3. Detail

3.1. Initialization

The value of vegetation coverage was randomly designed and changed in a range (0–30%). In each patch, seed densities follow a special equation provided in our previous study [A9]. The moving direction of seeds follows the frequency of wind directions in the experimental region [A10]. Moreover, the influence of grazing intensities on vegetation coverage was set following a previous study [A11].

3.2. Input data and submodels

The input data are shown in Table S2.

Table S2. Input data of this seed dispersal model

Variables	Values	Units	Variables	Values	Units
The frequency of wind from northern direction	10	%	The number of seeds	2000	seeds
The frequency of wind from southern direction	20	%	Running time	40	steps
The frequency of wind from eastern direction	10	%	Vegetation coverage	0-30	%
The frequency of wind from western direction	10	%	Heavy grazing damage on vegetation	85.9	%
The frequency of wind from southwestern direction	20	%	Moderate grazing damage on vegetation	45.9	%
The frequency of wind from northwestern direction	10	%	Light grazing damage on vegetation	23.7	%
The frequency of wind from southeastern direction	10	%	The frequency of no wind	33	%
The frequency of wind from northeastern direction	10	%			

References of Appendix

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