A model for seed dispersion and vegetation growth

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Abstract. The study of processes associated with vegetation grow is very important to understand the dynamics of flooded ecosystems and their sustainable management. We present a cell-centered individual-based probabilistic model for the dynamics of tree-populations, that is further tailored towards the environmental conditions present in the Amazon floodplains.

1. Introduction
The study of processes associated with vegetation grow is very important to understand the dynamics of flooded ecosystems and their sustainable management [5]. In the Amazon floodplains, the seed dispersion process is strongly influenced by the annual flood. Seed dispersion and germination occur in the beginnings of a plant's life cycle and variations in them strongly affect the distribution, structure and dynamics of tree populations [4].

Although difficult to collect in the Amazon floodplains, due to environmental conditions, information about the production and deployment of seeds by trees, as well as their germination, is available. Existing models for vegetation dynamics usually consider environmental factors as age, height, seed distribution, mortality, shadowing and the flood in an integrated manner [2, 1].

We propose a computational, non-deterministic but probabilistic, model to study the impact of seed dispersion and germination on the behavior of tree-populations. This model is data-meagre, that is, it requires the collection of very little data to estimate its parameters, that are mostly probabilities and rates [3] .

This model is for generic populations of trees. Annual flood effects will be considered implicitly, through the data and parameters used, that originate from field research in flooded areas and by considering in the algorithm some details of the tree-growth and the seed-dispersion processes that are characteristic of the flooded areas. Our model also considers a simplified, minimally necessary, age structure and light incidence. Despite being probabilistic, the model behaves similarly to usual population models with finite carrying capacity.

2. The Model
The model for the dynamical behavior of a tree population highlighted here is computational, having no mathematical counterpart, non-deterministic and parametrized by probabilities and rates estimated directly from field data. It is a hybridization of cellular automata and life-cycle

models. Besides, it contemplates seed dispersion and the influence of light as the main source of interaction among individuals. Since interactions are represented by means of probabilities as well as growth and mortality rates, the introduction of other species of vegetation in the model is straightforward. It is enough to consider the dependencies of parameters of each population on the density of other species individuals.

To represent the spatial distribution of seeds and the growth of germinated seeds, our model makes use of neighborhood-regions containing mature trees. In them, mature-trees influence the germination of seeds and the growth of young trees. The probability of a seed settling at any point in the first neighborhood varies only with the distance from the mature tree. We make the hypothesis that every year each mature tree produces a fixed number of seeds that are distributed in accordance with this probability density. Seed-germination and the growth process depend on solar light availability. In particular, since the canopy of mature-trees contain sufficiently dense leaves and twigs structure, the light permeating the canopy will vary differently along the day depending on how close a point on the ground is and influence the growth of surrounding trees underneath. Indeed, for most species, the closer a young-tree is from a mature-tree, smaller will be its chances to survive. In some cases it may occur the death of these individuals by shading.

We assume that the tree populations are constrained to a contiguous two - dimensional region C that is subdivided into rectangular non-intercepting cells. This is an individual based cellular model. In counterpoint, the temporal behavior of plant populations, grounded on individual's lifecycles is handled through compartmental models, parametrized by birth and mortality rates. The compartments are not uniform, represent the minimum lifecycle stadiums associated with different maturation time intervals that are needed. Special characteristics of the Amazon Forest flooded areas determine these stadiums and data collected there provide the model parameters.

2.1. Seed Distribution
The probability density function, $\mathcal{D}$, of a seed settling with medium distribution σ at a point P distancing r from a mature-tree is:

$$\mathcal{D}(r,\sigma) = \frac{1}{\pi\sigma^2} e^{(-\frac{r}{\sigma})^2} \tag{1}$$

The probability $\mathcal{P}(r,\sigma)$ of a seed to fall in a neighborhood dA is:

$$\mathcal{P}(r,\sigma) = \mathcal{D}(r,\sigma) \times dA \tag{2}$$

2.2. Light Incidence
In the model, light competition is represented by a mortality probability. We make the hypothesis that young-trees or mature-trees mortalities by suffocation μ_s is associated with local shadowing d_{ls}:

$$\mu_s = \mu_s(d_{ls}) \tag{3}$$

3. Numerical Results
Several tests were executed varying the values of the diameter of the settling-neighbourhood σ. The initial condition was kept fixed and has nine trees on the left of the region $\mathcal{C}$, that sit on different neighbourhoods. Figure 1 and 2 show the dynamic evolution of the population for two values of σ, for the first 200 years.

It is possible to observe that the seed dispersion parameters strongly influence the vegetation dynamical behaviour. For $\sigma = 4$, the vegetation is already in balance after 150 years occupying 100% of the region $\mathcal{C}$ while for $\sigma = 2$ the trees occupy only around 80% of $\mathcal{C}$ after 200 years.
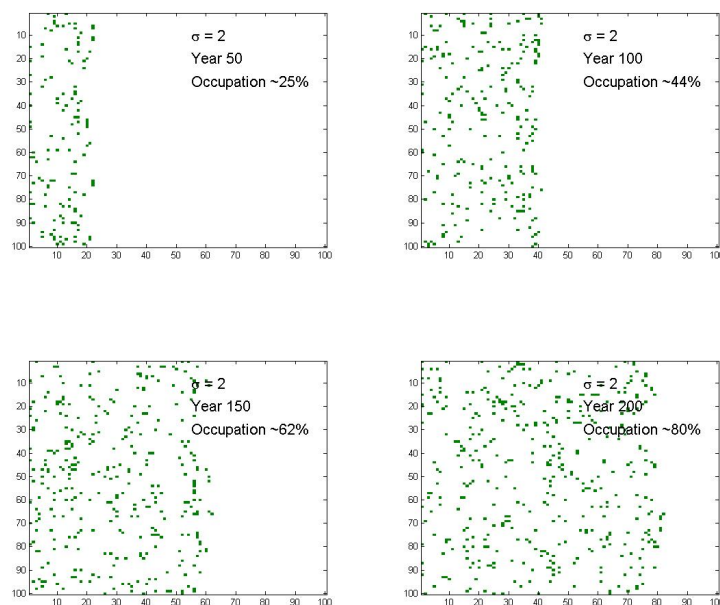
Figure 1. Spatial distribution of mature-trees in region $\mathcal{C}$ for $\sigma = 2$ and $t = 50, 100, 150$, and 200 yrs.
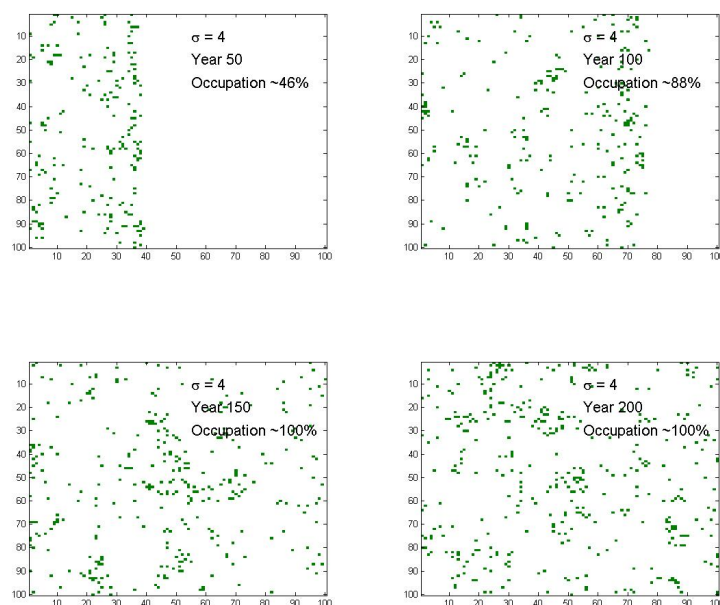

Figure 2. Spatial distribution of mature-trees in region $\mathcal{C}$ for $\sigma = 4$ and $t = 50, 100, 150$, and 200 yrs.

4. Conclusions

Although non-deterministic and probability-ruled, the model introduces is statistically sound showing reasonable freedom around a secular tendency that mimics deterministic population models of finite carrying capacity [3].

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Figure 3 shows the evolution of the total population along time for $\sigma = 2, 3, 4$ and 5. It is possible to observe that for $\sigma = 5$, the dynamical behavior reaches it steady state before 100 years.
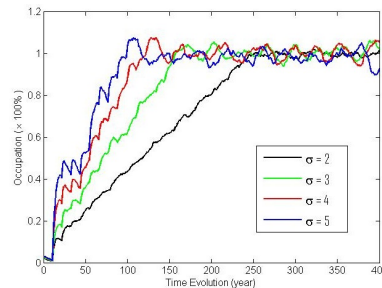

Figure 3. Time evolution of the total number of trees in the population, for the first 400 yrs and $\sigma = 2, 3, 4$ e 5.

On the other hand, for $\sigma = 2$, it reaches the steady state only after 200 years. This occurs because for $\sigma = 2$ the settling probability rules concentrate most seeds under the canopies of mature trees. The bigger the value of σ, the faster the population dynamics reaches the steady state, because initially most seeds settle outside the shading zone of mature trees. As the number of mature trees grow, it becomes more difficult for young trees to survive. Bigger the values of σ represent better flood influence in the seeds dispersion. In fact, the flood transports seeds to places distant from its mother-tree.

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