Attractor of a neutral individual-based forest model captures spatiotemporal structure characteristics of a mature tropical forest

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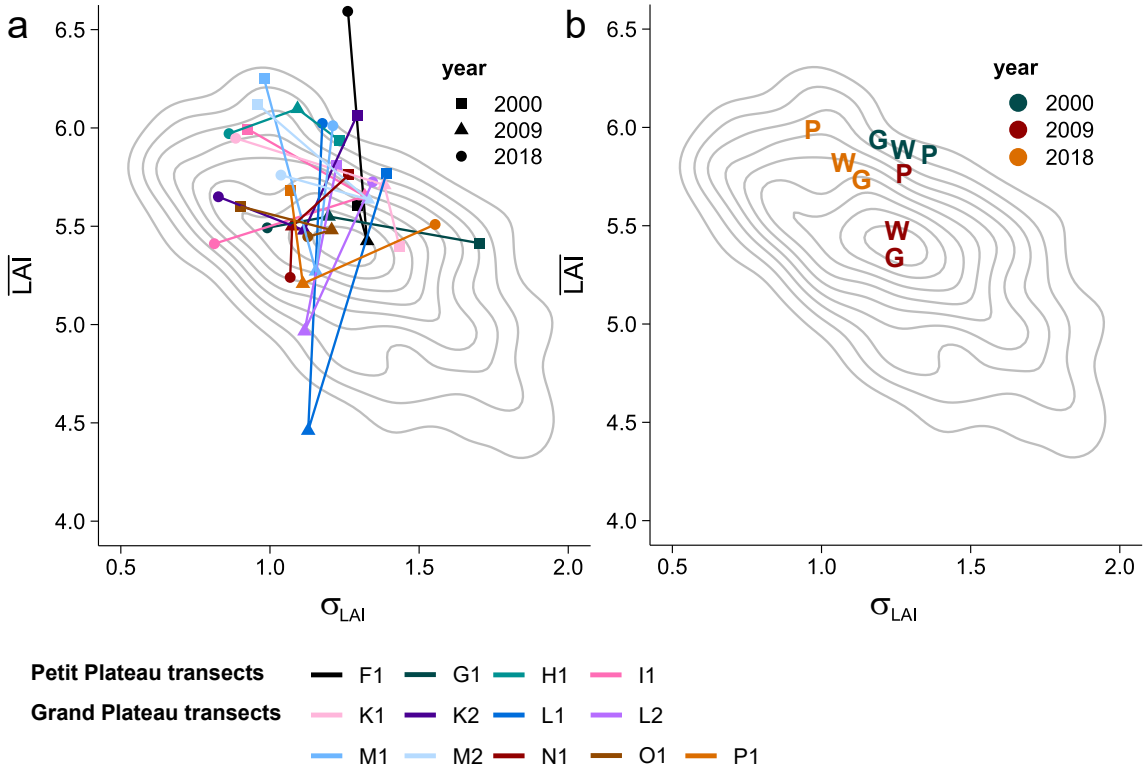
Abstract

Like other ecosystems, a forest never reaches a static equilibrium (climax), but ends up on a stochastic attractor, as a few dynamical systems approaches have shown. Here, we follow a tropical evergreen South American forest in French Guyana, which has not been anthropically perturbed for around 200 years, and then only in minor ways (and there have been no large scale perturbations since around 500 years ago). This study presents both experimental data and a modelling approach. Our data consists of measurements of the leaf area index (LAI) at high resolution along thirteen 512 m-long transects in July of 2000, 2009, and 2018. For each transect we plot the mean LAI ($\overline{\text{LAI}}$) against its standard deviation (σ_{LAI}). We find that each transect follows a trajectory in $(\sigma_{\text{LAI}}, \overline{\text{LAI}})$-space which is confined to an oval-shaped domain. A strong change is observed between 2000 and 2009, with lower $\overline{\text{LAI}}$ and higher σ_{LAI}, on average, hinting at temporal environmental degradation. However, the average values over all transects in 2018 show a quasi-return to the 2000 values. This is explained by a rainfall deficit in 2009, but does not exclude the possibility of a systematic drift in the future. In the modelling part, we improved upon the very simple cellular automata type model used in previous work by incorporating a more realistic description of tree life and death, and it successfully reproduces the dynamic behaviour of the real forest. The fact that such a simple model gives a very good description of the forest behaviour is strong evidence for the efficacy of a dynamical systems approach to the understanding of real forest ecosystem dynamics.



Level curves showing the cumulative distribution of points in $(\sigma_{\text{LAI}}, \overline{\text{LAI}})$-space from 10% (outermost curve) increasing in intervals of 10% to 90% (innermost curve) for 1500 years of simulation after reaching the stochastic attractor at year 500. **a** also shows trajectories of the $(\sigma_{\text{LAI}}, \overline{\text{LAI}})$ values of the thirteen Nouragues transects measured at 9 year intervals starting in July 2000. **b** shows the mean values of $(\sigma_{\text{LAI}}, \overline{\text{LAI}})$ for the Petit Plateau (P), Grand Plateau (G), and the whole station (W) in 2000 (grey), 2009 (red), and 2018 (orange).

Background

Even when considering just the trees, a tropical forest typically contains a non-uniform distribution of hundreds of species in various stages of development. Is it possible to summarize and follow the time evolution of the state of such a forest in a meaningful way using only a few variables? In a previous study we proposed using the leaf area index (LAI) taken at metre intervals along a 512 m-long straight line (called a transect) through the survey area. The leaf area index is the effective number of leaves vertically above a particular point a metre above the forest floor and typically varies between 0 (no treee cover) and 8. It is relatively easy to measure using a cheap hand-held device. The variables chosen were the mean LAI ($\overline{\mathrm{LAI}}$), the standard deviation of the LAI (σ_{LAI}) along a transect, and a third variable D related to the diameter of the largest trees along the transect.

In the previous study, we tested the use of the variables by taking transects from the four developmental stages of a tropical forest in Khao Yai, Thailand. We also devised a simple cellular automata model of a tropical forest from which we could measure the variables in an analogous manner. We could follow the trajectory in $(\sigma_{\mathrm{LAI}}, \overline{\mathrm{LAI}}, D)$-space of the forest as it grew from naturally afforesting grassland to the mature forest. The mature forest appeared as an ovoid region in $(\sigma_{\mathrm{LAI}}, \overline{\mathrm{LAI}}, D)$-space. It is the behaviour of the system within this stochastic attractor that we investigate in the present work. Note that for the mature forest, D varies very little, having reached its maximum value, and so can be dispensed with.

Key results

- 13 high-resolution leaf area index (LAI) transects in a pristine mature forest in French Guyana, South America were measured in July 2000, 2009, and 2018.
- The average of the LAI mean along transects was found to drop during 2009, which was a dry year, but recovered in 2018 when the rainfall was normal.
- Our cellular automata type model reproduces the real forest dynamics well.
- The field and model-generated data lie within a oval region which we interpret as the stochastic attractor of a dynamical system.

Related resources

[1] Chanthorn W, Ratanapongsai Y, Brockelman WY, Allen MA, Favier C, Dubois MA (2016) Viewing tropical forest succession as a three-dimensional dynamical system. *Theor Ecol* **9**, 163–172.