Research Proposal

Title: *The Fractal Structure of Treelines in High Mountains*

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Introduction:

The occurrence of tree species in high mountains usually ends abruptly at some elevation. This is the treeline. The appearance of treeline structures in such areas is a topic of interest to ecologists and climate scientists. These treeline structures exhibit a characteristic mainland-island structure, where the tree cover is continuous at lower elevations ('mainland') and fragmented at higher ones ('islands'). Theoretical predictions from percolation theory using simulation-based results obtained by studying two widely known types of models (the static Uniform/Gradient Random Map model and the dynamic Uniform/Gradient Contact Process model) suggest that the hull of the 'mainland' should be a fractal with dimension 7/4. This research project aims to test this hypothesis using satellite images of treelines and to develop simulation software that appropriately presents the gradient models as well.

Literature Review:

Several studies have investigated the transition from connected to fragmented vegetation across environmental gradients and scaling laws in ecotone geometry (Gastner et al., 2009). Recent research has also suggested that percolation theory predicts some universal features in range margins across environmental gradients (Juhász & Oborny, 2020). However, there is a lack of research that uses satellite images to analyse the fractal structure of treelines and its implications for species border delineation and climate change detection. Additionally, the existing simulation software of this population model in finite space does not capture environmental gradients.

Research Question and Objectives:

Does the fractal dimension of treeline structures support the percolation theory prediction of 7/4? Can we develop simulation software that appropriately presents the gradient models as well? The objectives of this research project are to develop a method for characterizing the fractal structure of treelines using satellite images, to evaluate the accuracy of the method in predicting the fractal dimension of treelines, and to develop simulation software that captures environmental gradients.
Main points:

- Cellular automaton for population dynamics simulation
- Modifiable contact process variables
- Percolation cluster identification
- Marking the hull of the giant cluster

Research Design and Methodology:

Satellite images of treelines will be obtained from publicly available datasets after careful consideration and thorough discussion with a cartographer specialist. A custom algorithm based on the existing literature in the field will be implemented to calculate the fractal dimension of the treeline structures. The potential limitations of the data and methods will be cautiously addressed. Additionally, simulation software will be developed (involving visualization of population dynamics models in finite space, implementation of algorithms for detecting the so-called 'giant component' of the population, and for the delineation of its 'hull') that captures some environmental gradients and appropriately presents gradient models. The results of the simulation software will be compared with those obtained from real-life ecological data.

To be able to effectively test our hypothesis and to maintain the possibility of extending this research topic in the future we have decided to use the following methodology:

- Programming language: Python (desktop application);
- Build a compact, yet easily extendible framework for the research topic;
- Using our python program and multiple process variables we will test the hypothesis.

Expected Results:

We expect to find that the fractal dimension of treeline structures supports the percolation theory approximation of 7/4. The proposed method for characterizing the fractal structure of treelines using satellite images is expected to be accurate, with potential applications in species border delineation and climate change detection. Additionally, the simulation software is expected to capture environmental gradients and appropriately present gradient models.

Key Milestones:

1) Simulating the Gradient Random Map model
    a. Implementing the population growth model in python;
    b. Identifying percolation clusters;
    c. Delineating the hull of the 'giant component';
    d. Estimating the fractal dimension;
    e. Studying the so-called finite-size effect;
    f. Examining the effects of different methods of (d) and (e).
2) Simulating the Gradient Contact Process model
    a. Implementing the population growth model in python;
    b. Applying 1.b-d on the population data yielded by these simulations;
    c. Possible generalization of colonization and extinction rates in (a)
3) Analysing real-life ecological data
    a. Obtaining map data (consultation with a cartographer specialist)
    b. Transforming this data into pixel maps
    c. Constructing binary maps from this data by methods of image analysis
    d. Applying 1.b-d on this data
    e. Summarizing the treeline (depending on the results of the analysis)

Conclusion:

This research project aims to test the hypothesis that the hull of the treeline mainland in high mountains is a fractal with dimension 7/4, using satellite imagery. By developing a feasible method for characterizing the fractal structure of treelines, this project has the potential to contribute to the precise delineation of species borders and the detection of population shifts due to climate change. The project will also involve the development of simulation software that includes environmental gradients to test the fractal result on simulated data. With the guidance of our supervisor and her team, we are confident that this project will make a valuable contribution to the field of plant ecology and theoretical biology.