Uncovering spatial feedbacks at alpine treeline using spatial metrics in evolutionary and simple simulations.

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Biography

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Introduction

At alpine treeline, trees and krummholz forms affect the environment in ways that increase their growth and reproduction. We assess the way in which these positive feedbacks combine in spatial patterns to alter the environment in the neighborhood of existing plants. Areas of alpine tundra are susceptible to encroachment by woody species as climate changes. Moreover, the overall process by which one type of vegetation moves into another is relevant to general processes of plant invasion. The importance of spatial pattern has been recognized, but the spatial pattern of positive feedbacks per se has not been explored in depth.

We concentrate on finer-scale spatial patterns than previously attempted because of the scale of the processes observed in ongoing work. We examine the roles of the processes of positive feedbacks in creating the patterns of patchy and fingering krummholz and small trees. We combine finer spatial resolution in simulations with fine scale multispectral imagery.

We test hypotheses on the ecological processes and modeling of ecotones. Where the processes at ecotones have been hypothesized, and patterns have been analyzed, this attempt to examine spatial detail at a finer scale will allow us to explore nonlinearities in responses and the potential for the organization of ecotone areas as complex adaptive systems. By linking the biogeographical phenomena of ecotones to the body of work on complexity theory, we hope to improve our understanding of the organization of biome boundaries and to make a geographical contribution to the theory. This work will also be germane to the idea of ecotones as indicators of the impacts of climatic change because of the potential nonlinearities induced by positive feedbacks.

Methods

We develop a cellular automaton (CA) that uses genetic algorithms and programming to uncover the spatial patterns of feedback processes. A CA captures the processes as parsimoniously as possible as simple rules. Genetic algorithms and programming are used so that the weights and rules change in response to how well the simulations produces patterns similar to observed patterns. Spatial metrics developed in landscape ecology are used in the fitness functions. Much of the analysis compares the weights and rules created in different conditions. Different patterns of abiotic (pre-feedback) site quality, static patterns of vegetation, changing rates of abiotic site quality (e.g., climate), and different scale relations are examined through the weights and rules created.

We create specific gradients of site-quality on a grid as initial conditions representing the fundamental niche of a species. This grid slides upslope indefinitely and we only study the ecotone portion. Patterns of site quality are derived from theoretical and empirical models. The site quality is then used as a basis for establishment by iterative testing against random numbers. The site quality gradient is modified by the presence of surrounding trees. The number of trees and their distances, patch sizes, shapes, and orientations in a neighborhood are all used to affect the site quality of a cell. The weighting of these factors in determining the change in site quality is determined through a genetic algorithm. Selection among which factors to consider is similarly handled in genetic programming.

Results

The genetic algorithm approach was found to have limitations. It was unable to reliably settle on a single weighting pattern among many simulation runs. The factors to be weighted are too correlated for a consistent separation to be made, given the degree of stochasticity built into the simulation.

The genetic algorithm approach did reveal, however, that linear feedbacks between these factors and tree establishment were an insufficient description of the process. A nonlinear model had to account for both negative and positive feedbacks with distance decay – at differing rates – from extant trees. A simple prototype model indicates that the array of patterns seen at treeline can be generated from a single simple model showing self-organized criticality irregularly in the dynamics. This model indicates feedback between the rate of advance and the spatial pattern at treeline in both its fractal dimension and number of patches. The power-law slopes for the history of fractal dimensions and the advances of trees indicate self-organization. The power-law slopes for the distribution of patch sizes in each iteration show dynamics in the self-organization.

We conclude that both positive and negative feedbacks together create the nonlinear process that allows treeline to change pattern and rate of advance in ways that cannot be strongly tied to rates of climatic change.