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Forest Stability Analysis Through Percolation Theory and Mycorrhizal Networks

Mycorrhizal fungal networks occur where mycorrhizal fungal mycelia link the roots of multiple plants creating a connected network. Mycorrhizal fungi are then able to promote the interplant transfer of minerals, carbon and water. The mycorrhizal fungus mycelia have been shown to shuttle carbon, nutrients and water from mature trees and nutrient dense areas to nutrient limited trees such as to seedlings. Mycorrhizal networks allow seedlings to mature underneath the tree canopy. A feat unattainable without the aid of the fungal partners. Here we analyze the stability of forest communities, by examining the forest connectedness and ability to rebound after disturbances as facilitated by mycorrhizal networks. Within a forest community, a Hub tree is a tree who's roots are highly connected to many neighboring tree roots by mycorrhizal fungal mycelia. Hub trees for mycorrhizal networks have been shown to even out resource availability and create favourable local conditions for tree establishment. These Hub trees are thought to be fundamental in forest community restoration and development.

It has been shown that the stability of forest ecosystems is in the existence of biological networks. By forming a mycorrhizal network, the community becomes more stability and regenerates following a disturbance more quickly. In particular, it has been thought that if hub trees remain after a disturbance, along with their fungal symbiotic partners, then forest regeneration is achieved more quickly. Here we mathematically explore these ideas with the aid of graph and percolation theory.

A random graph is a collection of nodes (or verticies) linked together at random by lines (or edges). Graph theory has been used to study a wide variety of real-world networks such as the Internet, social networks, power grids as well as epidemiological networks. We show that graphs and percolation theory may be useful tools at modelling the flow of nutrients and carbon between trees in a mycorrhizal network. And hence a useful tool for an analysis of forest stability. For this particular model, trees represent the nodes of the graph and the mycorrhizal fungal mycelia, which links the trees together, are represented by the edges of the graph. Through percolation theory, it has been suggested that if connection patters are chosen appropriately, a network can be made highly resilient to random deletion of nodes. Alternatively they might be susceptible to attacks, which specifically target nodes of high degree (ie. Hub trees).

The connectivity of the forest community and hence the robustness of the graph is analyzed after random depletion of edges and nodes. By assuming a relatedness between tree connectedness and maturity (and thus ability to produce carbon and acquire nutrients), we are able to quantify the robustness (ie. the ability to regenerate after a disturbance) of forest communities. As in other studies, by deriving the probability generating functions specific to the mycorrhizal network, we are able to calculate the average large component following a random deletion, as well as targeted deletion of nodes and edges. This provides us with an analysis of forest stability and the importance of key hub trees within communities. Such findings may be useful in adjacent disciplines such as forestry where quick forest regrowth is economically and ecologically favourable.