Brazilian Pepper, Fire and the Invasibility of Pine Savannas
Exploring Nonlinear Effects through Simulation

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Summary

Interactions between fire and invasive species may contribute to the vulnerability of ecological communities to invasion. Invasive species may alter fuel characteristics and fire regimes to facilitate their continued invasion. A positive feedback between fire frequency and invasive species abundance may result in conversion of ecological communities to alternative stable states once an ecological threshold is crossed.

Pine savannas are fire dependent communities that are frequently invaded by the exotic shrub Brazilian pepper (*Schinus terebinthifolius*) in southern Florida. Brazilian pepper, which is intolerant of fire, can displace the native community, transforming open pine savannas to Brazilian pepper thickets. We propose that the invasion of pine savannas by Brazilian pepper is facilitated by the low flammability of Brazilian pepper fuels, which act to reduce fire frequency in the landscape.

We use a computer simulation model to demonstrate that frequent, low-intensity fires, typical of pine savannas, can limit Brazilian pepper density to low levels. As fire frequency decreases, however, a threshold is crossed that results in the rapid conversion of pine savannas to Brazilian pepper stands. As the strength of the nonlinear relationship between Brazilian pepper and fire probability increases, the location of this threshold is moved to higher fire frequencies.

Model

We simulate pine savanna dynamics using a cellular automata model operating on a 100 x 100 grid. Each cell represents a discrete area (e.g., 10 m x 10 m) and can be in one of four states: grass, pine, hardwood or invasive (Brazilian pepper). The landscape is first initialized, and then updated each time step. Two primary processes occur within each time step: vegetative succession and fire spread. Vegetative succession is defined by transition probabilities between cell states, and this transition probability is dependent on neighborhood composition. Fire spread across cells is determined in a similar manner: the probability of a cell burning is a function of the focal cell and the state of neighboring cells. A model run is completed when a maximum number of time steps is reached or when the landscape reaches a stable composition.

The model is coded in the Java programming language using the IntelliJ Integrated Development environment. The model contains nine classes that define landscape behavior, cell behavior, statistical analysis, GUI display/interaction and file I/O. We use CERN's Colt library to generate random distributions. Open source R code was translated to Java to provide functions for spatial analysis.

Figure 1

The GUI interface and initialized landscape for our simulation model.

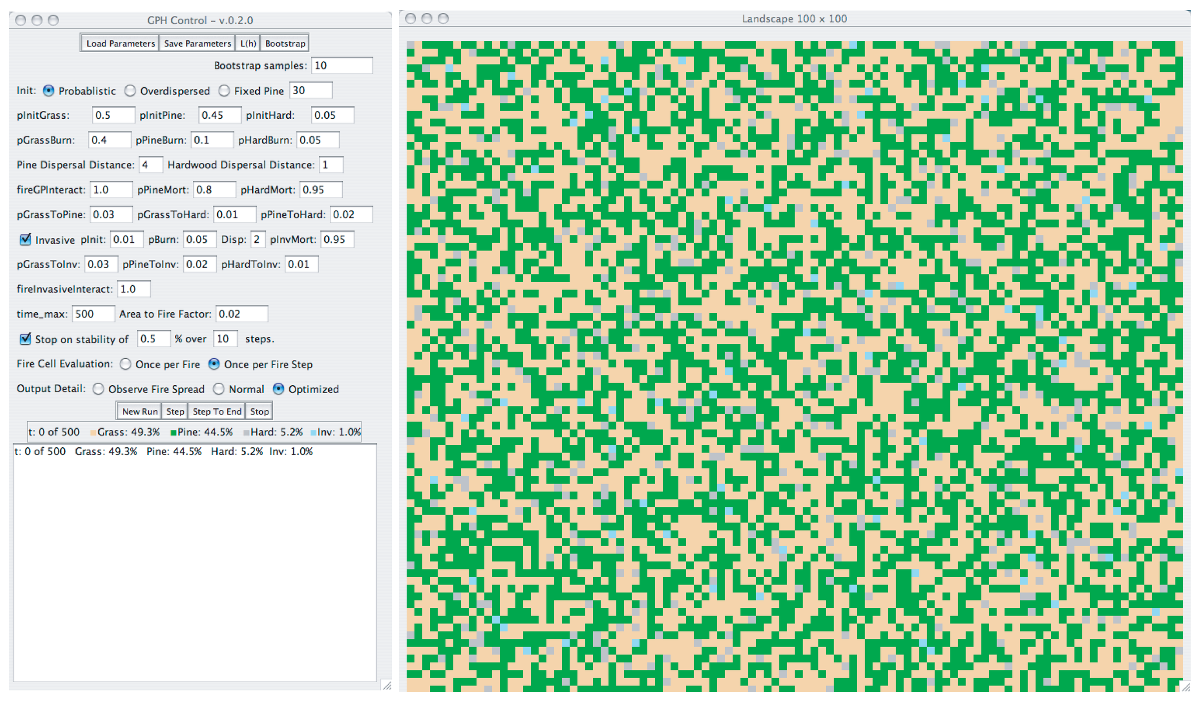


Figure 2

Vegetative change in response to succession and fire are described below. Cell transitions between vegetative states are shown for a cell that has not burned (i, below left) and for a cell that has burned (ii, below right). The width of each arrow is proportional to the probability of the transition occurring. In panel ii, the font color and size are proportional to the probability of that cell type burning: large font size and red color correspond to increased probability of burning. In addition, the transition probability of each focal cell is modified by the composition of neighboring cells.

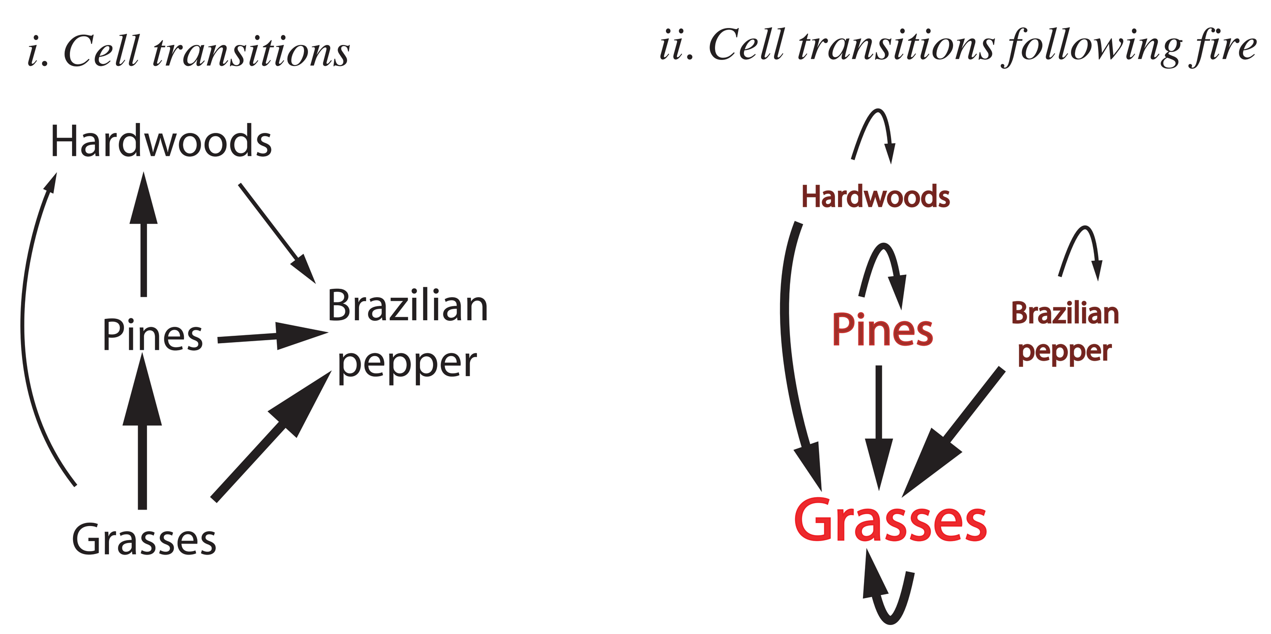


Figure 3

The invasion of pine savannas by Brazilian pepper exhibits a nonlinear response to changing fire frequency: As the number of fire ignitions decreases, a threshold is crossed where the ecological community rapidly shifts from a pine savanna dominated by grasses and pines to one dominated by Brazilian pepper. The location of the threshold shifts to higher fire frequencies (i.e., more fire starts) as the feedback between Brazilian pepper and fire increases in strength.

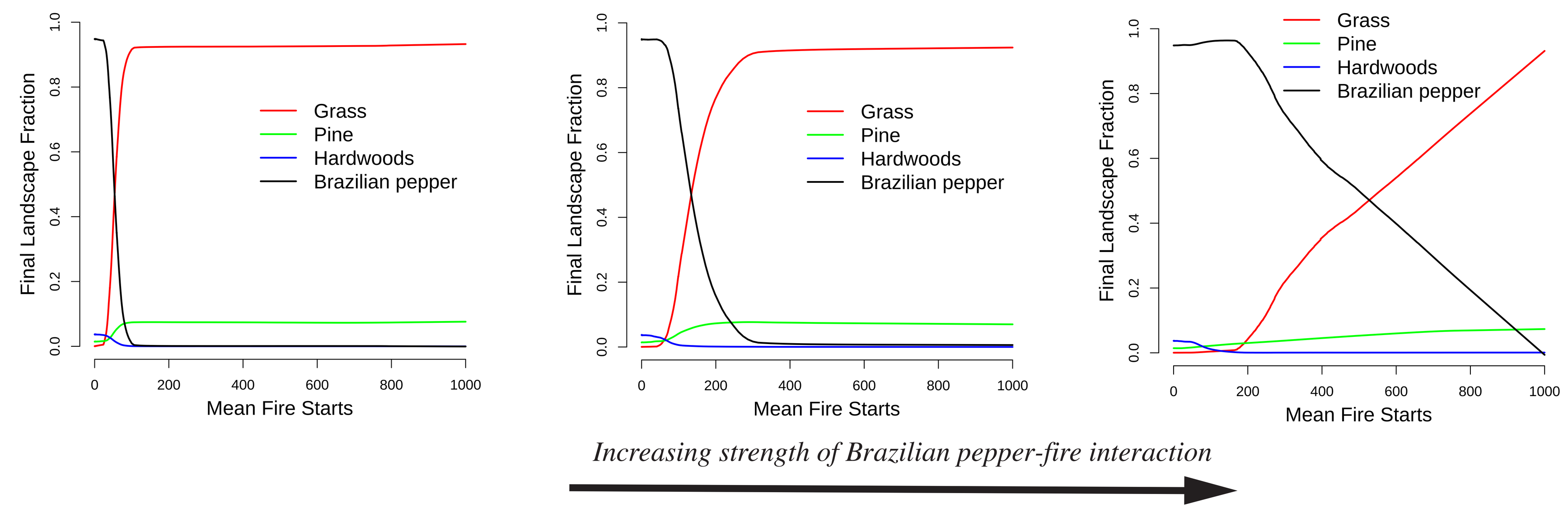
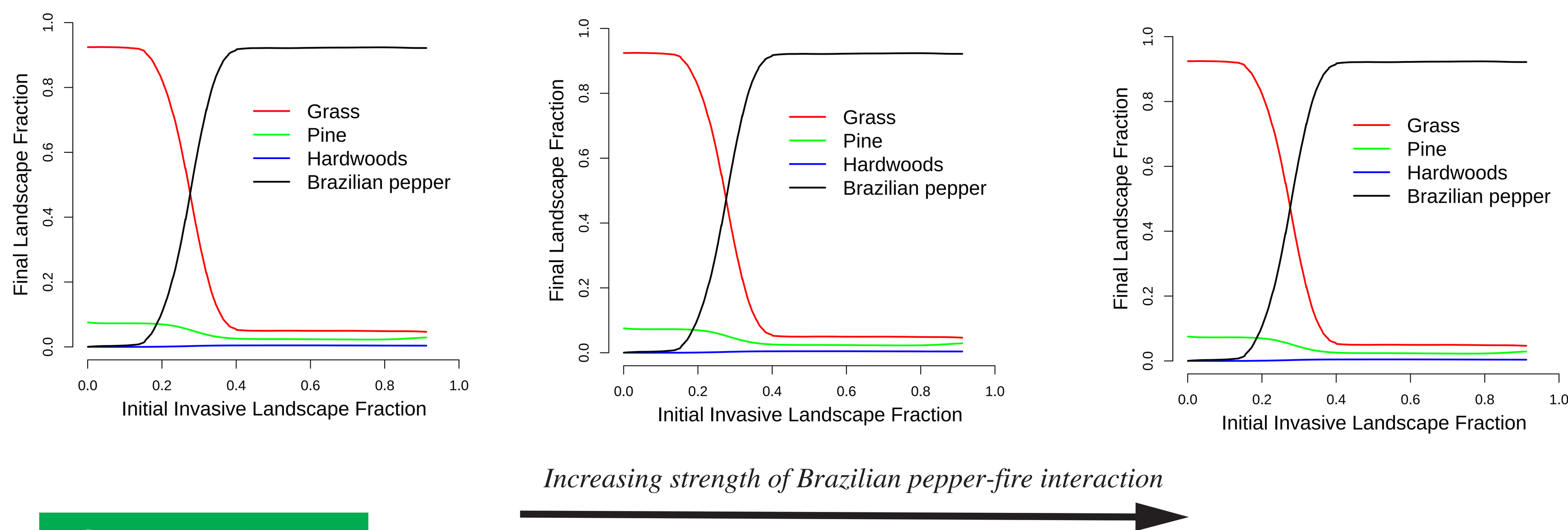


Figure 4

The composition of the pine savanna community responds nonlinearly to the initial abundance of Brazilian pepper. The ecological community is insensitive to increases in Brazilian pepper abundance until a threshold is crossed where community composition rapidly shifts from a pine savanna to a Brazilian pepper dominated community. The location of the threshold is relatively insensitive to the strength of the feedback between Brazilian pepper and fire.



Conclusions

Feedbacks between fire and invasive species can lead to the rapid transformation of communities to alternative stable states once an ecological threshold is crossed.

We identify two potential ecological thresholds in pine savannas with respect to Brazilian pepper invasion: (1) Decreasing frequency of fire in the landscape and (2) increasing initial abundance of Brazilian pepper. When these thresholds are crossed, native pine savannas are rapidly transformed to Brazilian pepper dominated communities.

Both of these ecological thresholds result from feedbacks between Brazilian pepper and fire. Infrequent fires allow the fire-intolerant Brazilian pepper to become increasingly abundant, reducing fuel loads, since Brazilian pepper has relatively low flammability, and thus lowering the probability of subsequent fires. Reduced fire frequency promotes further increases in Brazilian pepper abundance.