How the Thousand Cankers Disease and the Emerald Ash Borer will Alter the Roemer Arboretum's Tree Diversity: A Preliminary Approach

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Abstract

I utilized the transect data from a 1999 study of the Roemer Arboretum to parameterize a transition matrix model that predicts the arboretum's future tree composition. I calculated the Shannon diversity index of the transect's adult-tree community to quantify both its observed and predicted changes in tree diversity. My calculated diversity indices suggest that, relative to its observed state in 1999, the transect will naturally transition into a more uniform tree composition (i.e. in the absence of outside disturbances). I then parameterized the transition matrix model to simulate the hypothetical (yet probable) introduction of the Thousand Cankers Disease (TCD): my predicted data suggest that, following a TCD outbreak, White Ash saplings will predominantly replace those felled Black Walnut trees. I then simulated the hypothetical (yet probable) introduction of the Emerald Ash Borer (EAB) insect to gauge how the degradation of the arboretum's White Ash population will impact its tree diversity. After comparing the diversity indices of the initial and predicted compositions, relative to the arboretum's initial state, my calculations suggest that a TCD outbreak will cause the arboretum to become almost twice as uniform in its tree diversity. In the event of both a TCD and an EAB outbreak, relative to the diversity index of a naturally-transitioned transect, the tree diversity would improve by a factor of one-third.

Background

The introduction of the China-native *Cryphonectria parasitica* fungus to forest communities along the US Eastern seaboard prompted a widespread blight in the early 20th century that caused the once plentiful Eastern-native American Chestnut to become functionally extinct. Today, the invasive Mexico-native *Geosmithia morbida* fungus is causing the widespread mortality of a similar caliber to the US's walnut tree species: the observed blight is known as the Thousand Cankers Disease (TCD). The *G. morbida* fungus is carried by the walnut twig beetle (~1.5mm in length), which greatly enhances the disease's virulence and infectious potential. These tiny beetles usually travel undetected between forest sites via firewood: more than 2,300 beetles were found within two firewood-sized logs from a Black Walnut tree in Missouri, 2011 (**Figure 1**). Despite recent quarantine efforts, should these beetles propagate into forest communities along the Eastern seaboard, the resulting blight could endanger yet another plentiful, Eastern-native species: the Black Walnut tree.

Conversely, an Asia-native beetle *Agrilus planipennis* – the Emerald Ash Borer (EAB) – is targeting every species of ash tree in North America (**Figure 2**). Its presence in upstate New York has felled populations of the Eastern-native White Ash and poses a threat those found in the Roemer Arboretum.

Figure 1: 23,040 walnut twig beetles were found in these two logs from an adult-sized Black Walnut tree in Missouri, 2011. The dimensions of these logs are approximately 14-cm in diameter and 45-cm in length.

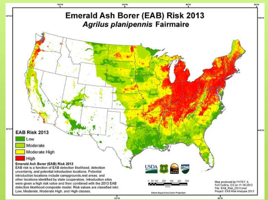

Figure 2: The invasive Emerald Ash Borer can kill an ash tree in as little as two years. Its long-distance propagation is caused by the transportation of EAB-infested ash firewood and timber.

Methods

Shannon Diversity Index:

$$H' = \sum_{i=1}^{S} (p_i)(\ln p_i)$$

Figure 3: High values of H are representative of a more diverse community.
H = the Shannon Diversity Index
P_i = fraction of the entire population made up of species i
S = number of species encountered
∑ = sum from species 1 to species S

Henry Horn's Transition Matrix Model:

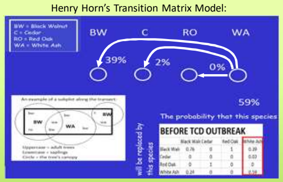

Fig 4: This model simulates forest succession by assuming that the probability of a canopy tree's replacement can be measured as a simple function of the relative abundance of sapling species found beneath its canopy. Note that this method offers a preliminary approach to predicting the arboretum's succession: A model that utilizes data from a greater area and accounts for individual species replacement probabilities would yield a more realistic simulation.

Hypothesis

The introduction of the Thousand Cankers Disease and the Emerald Ash Borer into the Roemer Arboretum will improve its tree diversity in later generations. The Black Walnut and White Ash species will leave gaps in the canopy that will be replaced by a more diverse population of trees.

Why is biodiversity important?

- Healthy biodiversity within an ecosystem supports a multitude of natural services: food, improved climate stability, pollution breakdown and absorption, resilience to a variety disturbances, etc.
- A loss in biodiversity weakens the connections between organisms in an ecological network: many species depend on one another for survival
- If a singular tree species dominates a forest stand's canopy, then a disease that exclusively targets and terminates that single species will cause sunlight to become promptly available for the dynamic basal vegetation below. If shrub vegetation outpaces the growth of nearby tree saplings, for instance, then the ecosystem itself can transition into that of a tree-less shrubland. This process is known as secondary succession

Observations

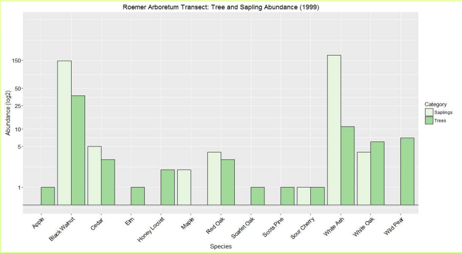

Figure 6: A tree is considered an adult if it is > 5" in diameter. The transect data suggest that the majority of the arboretum's overhead canopy is dominated by adult-sized Black Walnut trees. White Ash is the second most abundant adult-sized tree species in the transect, yet there exists more than three times as many adult-sized Black Walnuts as adult-sized White Ash trees. Conversely, the majority of the transect's basal and mid-story area is shared by both Black Walnut and White Ash saplings. Since White Ash saplings share the majority of the transect's basal and mid-story area, I hypothesized that the White Ash will most likely replace Black Walnuts in the event of a Thousand Cankers Disease outbreak.

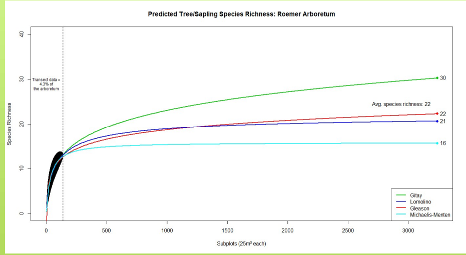

Figure 5: The arboretum's transect consists of 138 $25m^2$ subplots, and covers approximately 4.3% of the arboretum's 20 acres. 3100 more subplots – 3238 in total – would be necessary to cover the entirety of the arboretum's surface area. 13 tree species were observed in the transect; I used these area and species data to parameterize three species-area models formulated by Michaelis-Menten (1913), Gleason (1922), Gitay (1991), and Lomolino (2000) respectively. Averaged together, my results suggest that a potential 22 tree species exist in the arboretum. Relative to the other models, the Gleason model also measured highest in AIC (a goodness of fit measure), which predicts a value of 22 species in the arboretum. My results suggest that 9 potential tree species in the arboretum were either unobserved or nonexistent in the arboretum's transect.

Acknowledgements

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Results

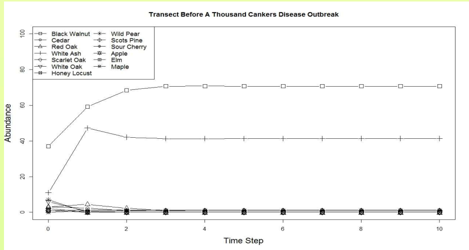

Figure 7: Each time step represents an arbitrary length of years necessary for the transect's tree populations to be naturally replaced. This method assumes that all tree species have a singular lifespan. Time step 0 represents the initial state of the transect in 1999: I measured its diversity index to be 1.71, and my model predicts that the index for its proceeding generation would be 1.00. The discrepancy in diversity indices suggests that the arboretum's forest community is becoming increasingly more uniform in tree diversity.

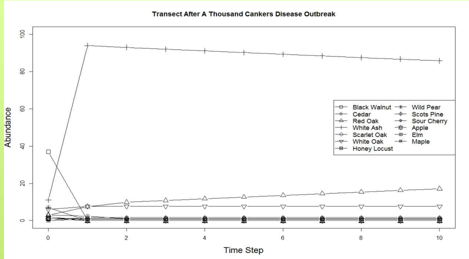

Figure 8: Time step 0 still represents the transect's initial state in 1999, whereas time step 1 represents its state after a TCD outbreak. My model suggests that, in the event of a TCD outbreak, the White Ash will effectively replace Black Walnut trees. Compared to the diversity index of 1.71 at time step 0, the transect following a TCD outbreak would become more uniform with an index of .80.

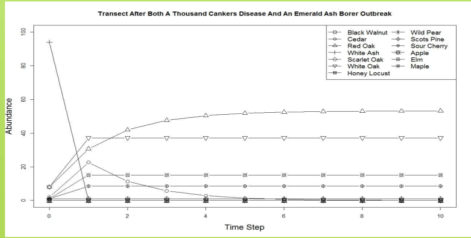

Figure 9: Time step 0 represents the same predicted tree composition of the transect after a TCD outbreak from time step 1 in **Fig. 8**. The data at time step 1 on this graph represent the predicted tree composition of the transect if an EAB outbreak were to occur following the TCD outbreak. My model suggests that the tree diversity index of the transect following a TCD and an EAB outbreak (in that order) is 1.58. The transect will therefore become more diverse relative to the predicted 1.00 diversity index of the transect's naturally transitioning tree composition.

Conclusions

The diversity indices from the transect's predicted and observed tree composition suggest that the arboretum's tree community is naturally transitioning into a more uniform composition. Both the predicted tree diversity of the transect and its calculated diversity indices suggest that, in the event of a TCD outbreak, the arboretum's tree community will become more uniform relative to its naturally transitioning state. Conversely, in the event that both the Black Walnut and White Ash species are compromised by a TCD and an EAB outbreak (in that order), the transect's predicted diversity indices suggest that the arboretum will become more diverse than its naturally transitioning state.

References

Fig. 1: https://mdc.mo.gov/trees-plants/diseases-pests/invasive-tree-pests/thousand-cankers-disease/tcd-kills-black-walnut
Fig 2: https://blog.epa.gov/blog/2016/10/new-england-can-prepare-ash-trees-before-emerald-ash-borer-attacks/