The spatial structure of pine forests and their susceptibility to bark beetles

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Introduction

- Bark beetles are the largest source of biotic disturbance in the forests of North America and the most economically damaging pest.
- There is a striking difference between the two most common pine species in the United States with respect to bark beetle infestations. Loblolly pine is 3-118 times more vulnerable to the Southern Pine Beetle (*Dendroctonus frontalis*, SPB) than longleaf pine.
- Recent studies have shown that this pattern is not due to differences in tree defenses, SPB preference, or predation. Thus, the underlying reason remains unclear.
- We know that young stands (<30 years) are more vulnerable to SPB than older stands (>50 years).

Theoretical model

- SPB depend on aggregation pheromones to kill trees
- The integrity of the pheromone plume is affected by the canopy structure
- Stands with high basal area and low nearest neighbor distances (NND) will have greater pheromone plume integrity. Hence, SPB will have enhanced attack efficiency, and these stands will be more susceptible
- Risk of SPB attack decreases non-linearly as NND increases and basal area decreases (Fig. 8)

Hypothesis

- Young loblolly stands will have the highest basal area and smallest NND.
- Basal area will decrease with age, and NND will increase with age
- Tree spacing differences between loblolly and longleaf could account for the differences in SPB pestilence

Methods

- I sampled 8 even-aged loblolly and 8 longleaf stands in the Kisatchie National Forest in Louisiana, USA.
- I used hierarchical sampling of transects within stands with the intent to have a true random sample for statistical inferences while still obtaining many measurements of individual trees. Within each transect, I measured tree spacing, diameter (DBH), basal area, height, height to live crown, and canopy class of every fifth tree, and recorded a waypoint.
- I measured the same areas on the QuickBird satellite image by tagging every tree within 20 m of every waypoint and extracting the NND and SNND.
- Data on the spatial progression of an infestation in 2004 was provided from three stands in the DeSoto National Forest, Mississippi.
- I calculated Hanski's connectivity for each tree within the infested stands using the formula: $$S(j) = \sum_i e^{-\alpha * d(i,j)} * N(i)$$

Further research

- Simulate the spacing of trees in a stand given the frequency distribution of NND and SNND using multi-dimensional scaling
- Develop a probabilistic model to forecast the risk of infestation of a stand given its spacing
- Build SPB infestation risk into economic models of yield to recommend an optimal amount of thinning to forest managers

Differences in forest structure between loblolly and longleaf pine stands

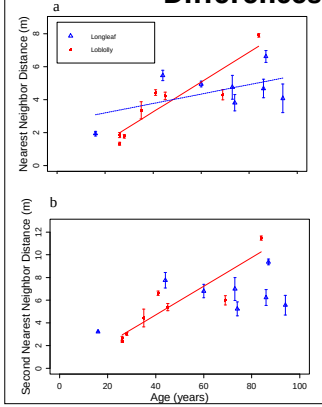

Fig. 1. Average nearest neighbor distance (nearest and second nearest) among pine trees in even-aged stands of longleaf and loblolly ranging in age from 16-94 years, as measured on the ground in the Calcasieu Ranger District of the Kisatchie National Forest in Louisiana, USA. Means ± SE (with SE based upon number of transects within a stand).

Age accounted for a significant amount of variation in both NND ($F_{1,12}$ = 21.6, p < 0.001) and SNND ($F_{1,12}$ = 18.4, p < 0.01).

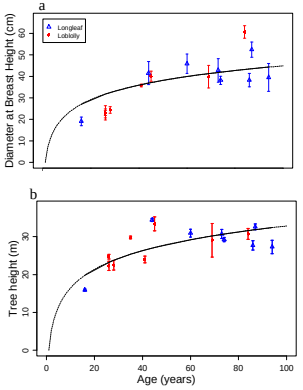

Fig. 2. Diameter at breast height (a) and tree height (b) among pine trees in even-aged loblolly and longleaf stands ranging in age from 16-94. Age accounted for a significant amount of variation in DBH ($F_{1,12}$ = 25.7, p < 0.001) Age also accounted for a significant amount of variation in height ($F_{1,12}$ = 18.4, p < 0.01).

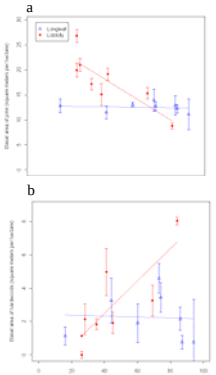

Fig. 3. Basal area of pine (a) and hardwoods (b) among even-aged pine stands. Basal area of pine decreased with age in loblolly stands, but remained constant in longleaf stands. There is a significant interaction between Age and Species ($F_{1,12}$ = 14.6, p < 0.01).

However, basal area of hardwoods increased with age in loblolly stands, and remained constant in longleaf stands. There was again a significant interaction between Age and Species ($F_{1,12}$ = 8.1, p < 0.05).

Modeling the spatial progression of an infestation

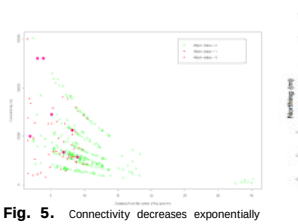

Fig. 5. Connectivity decreases exponentially with the distance to the center of the spot. New attacks (Attack status = 1) are initiated on the nearest unattacked trees

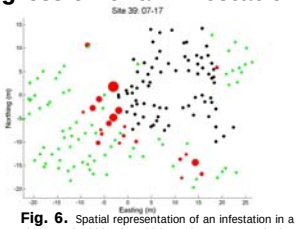

Fig. 6. Spatial representation of an infestation in a pine stand within the Chickasawhay Ranger District, DeSoto National Forest, MS. Black dots represent killed trees, green dots represent unattacked trees, and red dots represent trees under attack (area proportional to number of SPB on the tree).

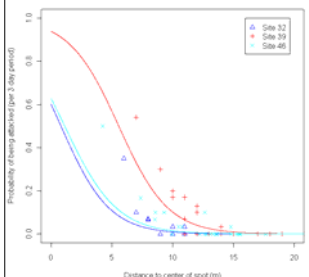

Fig. 7. Probability of attack a tree decreases with its distance to the center of the spot. Solid curves represent logistic regressions

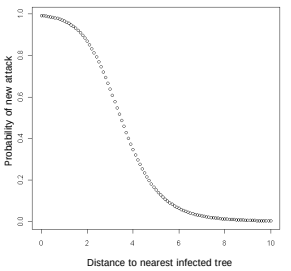

Fig. 8. Theoretical model for the relationship between the probability of a tree being attacked and its distance to the nearest infected tree

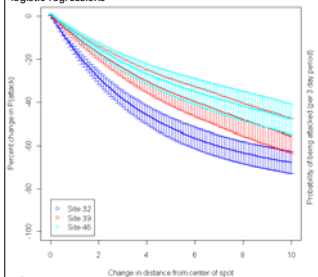

Fig. 9. Change in the probability that a tree will be attacked as it is moved away from the spot center. Probabilities are modeled based on the logistic fit between connectivity and probability of attack (Fig. 10)

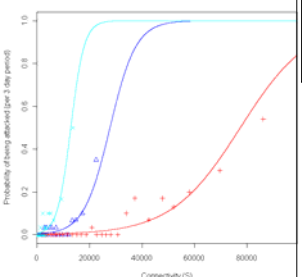

Fig. 10. Probability of a tree being attacked (per 3 day period) increases non-linearly with its connectivity. Site 39 was a much larger infestation than the other two sites

Is it possible to extract data on forest structure from a high resolution satellite image?

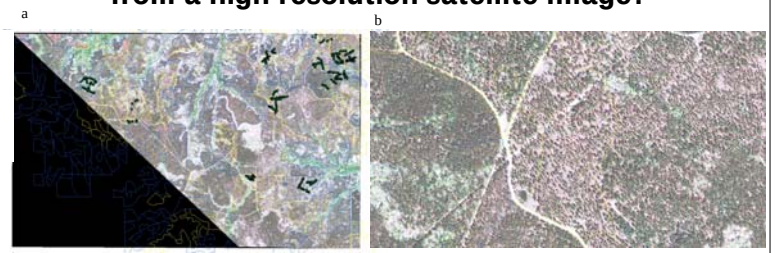

Fig. 3. QuickBird satellite image of the Calcasieu District of the Kisatchie National Forest, in Louisiana, USA. Green dots (a) represent trees that fell within 20 m of a waypoint and were tagged to assess the accuracy of the satellite interpretations (3,242 total). The resolution is 1:38000 (a) and 1:4000 (b)

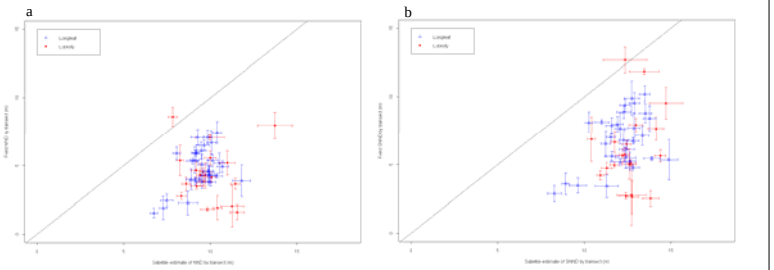

Fig. 4. Satellite estimates of forest structure from a QuickBird image of the Calcasieu Ranger District of the Kisatchie National Forest showed a consistent bias to overestimate NND (a) and SNND (b). There was a poor relationship between the estimate from satellite images and the true values as measured on the ground. The black line represents the line of equality (y = x).

Conclusions

- There are significant differences in basal area and spacing between longleaf and loblolly stands, which are consistent with known infestation risk, and could account for the observed differences in SPB pestilence.
- Hanski's connectivity index is a good predictor of the risk of a new SPB attack
- Simulations show that small increases in a tree's distance away from the center of the spot produce significant decreases in the probability of attack

Acknowledgments

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