Relative Growth Rate of Eastern White Pine Saplings as a Function of Density in an Old Growth Forest

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Abstract

Intraspecific competition between white pine saplings was investigated in an old growth forest near the University of Michigan Biological Station. This study was conducted to quantify the succession of Eastern white pine saplings (*Pinus strobus*) by measuring their relative growth rate as a function of density. Multiple plots were laid out to measure density, growth rate, and canopy cover. Our results indicate that the density of white pine saplings is negatively correlated to their growth rate, supporting the intraspecific competition theory. Canopy cover has no observable effect on relative growth rate or density. From this data, it can be inferred that white pine saplings are competing more for space and resources than light, and that this intraspecific competition imposes density-dependent mortality.

Introduction

Until 12,000 years ago glaciers cut through northern Michigan, reshaping the landscape, and selectively depositing a variety of soils (Heinen, 2010). Nutrient rich soils were piled into moraines while glacial melt water distributed sandy soils to the low lying areas, creating outwash plains. It is in these outwash plains that pines have their realized niche. The sandy soil is well drained and lacking in nutrients, which is favorable for pine tree growth (Barnes & Wagner, 2003).

Clear cut logging from the start of the 1840's destroyed much of northern Michigan's old growth forests. This destruction of old growth lead to a period of fires between 1880 and 1934, consequently altering the landscape and devastating undergrowth (Barnes, 2009). Select patches of trees survived, resulting in areas of old growth. Most of the old growth on outwash plains near Pellston, MI is red pine (*Pinus resinosa*), with some interspersion of Eastern white pine (*Pinus strobus*). However, as natural succession takes place, the Eastern white pine will likely replace the over-story red pines if wildfires remain absent (Barnes, 2009). This can be seen in the high density of white pine saplings in the forest. This growth is partially due to the greater shade tolerance of the white pine as opposed to the red pine (Barnes & Wagner, 2003).

These dense white pine patches give rise to high rates of intraspecific competition due to competition for limited resources such as light, space, and nutrients. Competition between neighboring pines will reduce their growth rates and increase their probability of death (Weiner, 1988). The growth rate of each tree is extremely important in determining which trees will reach the canopy. Only the fastest growing trees that can best utilize and obtain needed resources will do so, and outcompete surrounding trees (Harper, 1977). In this study, we measure the relative growth rates of white pine saplings in different forest densities. We hypothesize that higher densities of white pine saplings will have a negative effect on relative growth rate. Due to the fact that these trees are growing under canopy cover, light is expected to be a limiting resource. Thus, we hypothesize that increased canopy cover will have a negative effect on growth rate.

Materials and Methods:

Study Area

The study area is located in the woods off of Douglas Lake Road a half-mile east of Route 31 in Pellston Township, Emmet County, Michigan. This forest consists of mostly pine trees, including an area of old growth which is aged at over 120 years (Heinen, 2010). In this area, the forest canopy is made of mostly red pines and a smaller amount of Eastern white pines. Interspersed in the canopy are some trembling aspen (*Populus tremuloides*), American beech (*Fagus grandifolia*), and red maple (*Acer rubum*). The understory and lower canopy is dominated by intermittent dense growths of white pine seedlings and saplings. Ground cover consists of large amounts of bracken fern (*Pteridium aquilinum*), as well as low sweet blueberry (*Vaccinium angustifolium*). For the purposes of this study, understory will be defined as anything from 30 cm to 3 meters in height. Ground cover will be defined as all stems less than 30 cm tall.

Experimental Design

Approximately 200 meters into the forest north of Douglas Lake road, we laid out a 50-meter transect northward. Centered on this transect, seven two by two meter plots were laid out, with each plot separated by five meters. Using this method, we laid a combined total of seven transects and recorded data from a total of 49 plots.

Within each of these two by two plots, every white pine sapling between the height of 30 cm and 3 meters was measured and recorded. Measurements taken consisted of diameter at 6 inches, (Diameter Sapling Height, DSH), age, height, and growth rate of each of the last three years. Pine trees produce one whorl per year, so age was determined by counting the number of whorls a tree had. The distance between each of the top three whorls was found by using a measuring tape; this distance was considered to be the growth for each of the past three years. Relative growth rate was then calculated by dividing this length by the height of the tree. Then, the mean growth rate per year was calculated for each plot. All trees in the plot that did not meet our criteria were noted, as well as any large tree near the plot. Using this information, tree density was calculated by dividing the total number of trees by the area of the plot. Tree basal area (TBA) is the cross-sectional area at breast height measured in meters squared, and it is often used to estimate tree volumes and stand competition. Since we measured DSH in millimeters, TBA was determined by the following equation: . This was calculated for each tree in a plot, and then all of the basal areas were added together to give total basal area for the plot. Canopy cover for each plot was calculated using a spherical densitometer. All ground cover was documented as well.

Statistical Analysis

Several statistical tests were run in order to quantify the relationships between tree growth and many variables. A linear regression was run for the mean growth rate of each plot in each year versus the canopy cover. Then, we ran another linear regression on the mean growth rate in each plot versus the total basal area of each plot. We were able to see a trend of outlying data points upon creating scatter plots. These points were plots in which there were less than three trees. We took this density as a testable level for different intensities of intraspecific competition. Since this is the focus of our study, we removed these plots from our data set and retested this data with linear regression analysis. Next, we calculated the average TBA of all the plots. Using this data, we separated the plots into two groups: plots with above average TBA, and plots with below average TBA. Then we ran an independent t Test to compare the mean growth rate averaged over of the past three years of these two groups.

Results

When running linear regression tests among all 49 50 plots, there was no significant correlation between canopy cover and growth rate for any of the years. When canopy cover was compared to total basal area, no significant correlation was found in any plot. No significant correlation was found between mean growth rate and total basal area of the plots.

Despite the removal of outliers, no significant correlation was found between mean growth rate and canopy cover. With the outliers removed, total basal area was found to be significantly associated with mean growth rate in a negative, linear relationship. (2007 R^2=0.314, p=0.016, Figure 1a; 2008 R^2=0.384, p=0.006, Figure 1b; 2009 R^2=0.374, p=0.007, Figure 1c). The strongest correlation is shown in Figure 2 as the mean growth rate of the past three years compared to the total basal area (R^2=0.441, p=0.003). The independent t Test showed a significant difference between the mean growth rate of the past three years across pine tree plots of the two different TBA groups (p=0.007).

Discussion

Our hypotheses predicted that increased canopy cover would have a negative effect on the growth rates and basal area of white pine saplings. The results show no correlation between canopy cover and white pine sapling basal area or growth rate. This data shows several outliers as discussed in materials and methods. Due to competition being the focus of our study, these outliers were removed, and the data reorganized. When we redid the tests based on the reorganized data, the results still showed no correlation between canopy cover and sapling growth rate.

White pine trees are known to be moderately shade tolerant – growing well in partial shade. Under moderate light levels, the growth rate seems to be more limited by nutrient availability; while light is not a limiting factor at these light levels (Parker et al., 2004). This would explain why canopy cover did not have a measurable effect on our study.

As we hypothesized, the mean growth rate is negatively affected by density. The data showed a strong correlation between the variables over the past three years. More evidence for this hypothesis is shown by comparing the mean growth rate averaged over the past three years and the total basal area. This is a better estimate of sapling growth rate, minimizing stochastic variables, such as annual weather conditions.

The comparison of mean growth rates between high and low density plots further supports our hypothesis. It shows that the mean growth rate of saplings in less dense plots is significantly higher than that in denser plots. This indicates that a higher density may lead to greater intraspecific competition.

Our results provide evidence that growth rate and density of white pine saplings are directly correlated. This is due to competition for the limited resources that pine trees require. However, determining the limiting resource can be difficult. Since the amount of canopy cover did not have an observable effect on either total basal area (TBA) or growth rate, we think that light is not the limiting resource. Soil was assumed to be similar across our study area. This could be incorrect, because the areas of higher pine sapling growth could be areas of greater nutrient concentration. Earlier studies conducted on resource limitation in tree seedlings indicate that the white pine is sensitive to variation in soil nutrient availability (Canham et al., 1996). Therefore, we should have accounted for soil variation in our study, since such variation can cause micro-environmental differences. Since our study indicates that density negatively affects sapling growth rate, it appears that the saplings are competing for space. This could be more thoroughly tested in future experiments, as well as continuations of this experiment.

Our results give some insight into the growth of white pine saplings. Faster growing trees are larger in size, which is an initial competitive advantage (Wilson, 1988). Based on our results, we predicted that the saplings which grow faster compared to surrounding trees would have a greater chance of reaching maturity. Once these saplings reach the next canopy level, they are able to outcompete surrounding saplings for resources, causing density-dependent mortality, indicative of a type III survivorship curve (Harcombe, 1987). Pines appear to have evolved this way in order to provide a buffer against faster growing hardwoods (Hibbs, 1982). This buffer keeps hardwoods away from a central pine. This allows the pine sapling to survive by preventing over-shading from the faster growing hardwoods.

Although this study provided no evidence toward canopy cover having effects on the basal area or growth rate of white pine saplings, more research should be done to further test this. The use of two by two meter plots is convenient when quickly taking multiple plot samples and predicting canopy cover, but it is also limiting. The small size of the plot restricts the accuracy of each recorded sample as well as limiting the distribution area. In future studies, larger plots should be taken in a greater quantity and canopy cover should be measured at each sapling.

Future experiments could help to provide more information to support or reject our hypotheses. Continuing this experiment for many years could result in important information on forest succession. If this experiment is followed up 10 years in the future, we could determine which trees survived, and the factors that contributed to their survival. In addition, laboratory experiments on sapling growth rate across different densities would help to filter out stochastic or confounding variables such as microhabitat differences and nutrient limitations. The combination of laboratory and field experiments would allow more specific variable manipulation.

Our study suggests that intraspecific competition occurs in white pine saplings. This competition is more intense as sapling density rises. Studying intraspecific competition between white pine saplings should help to improve the understanding of future forest composition and management strategies.

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Figures

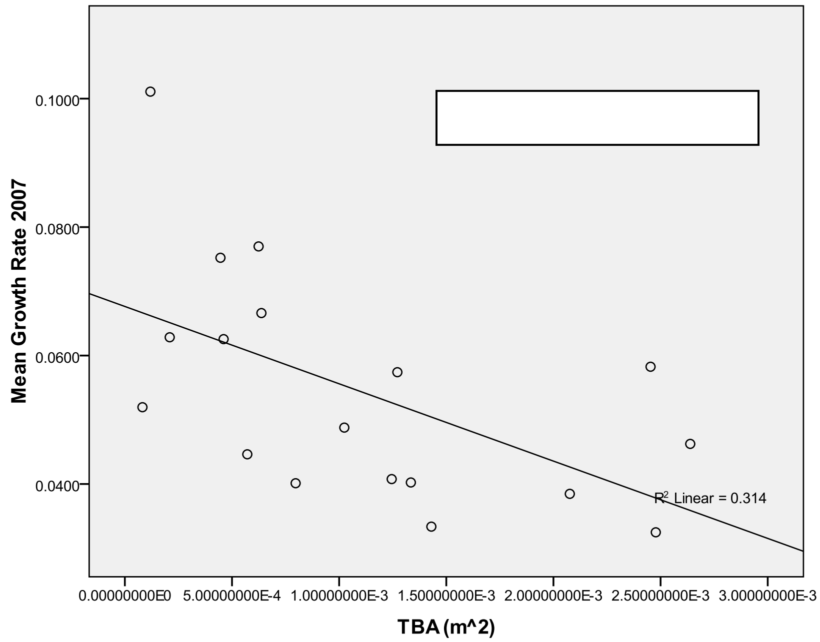

Figure 1a

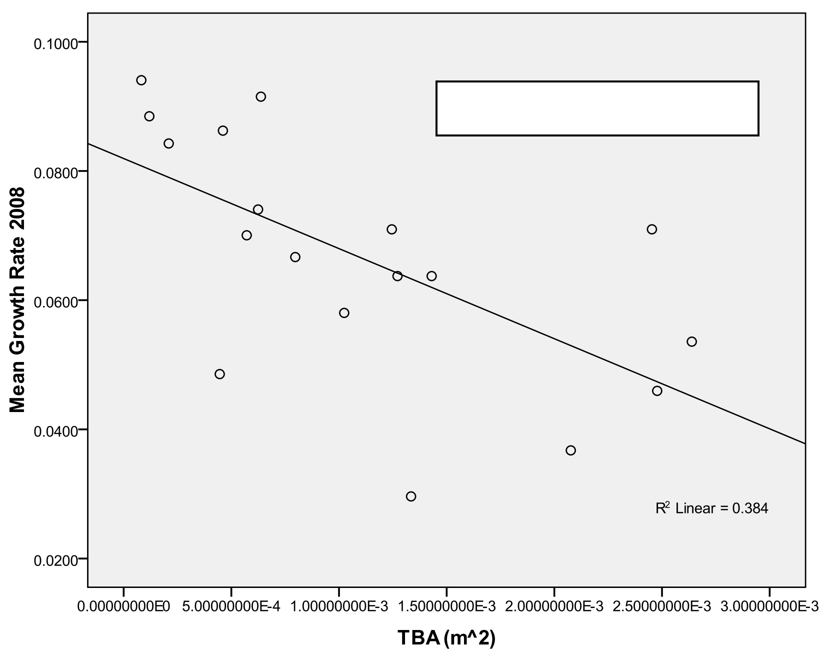

Figure 1b

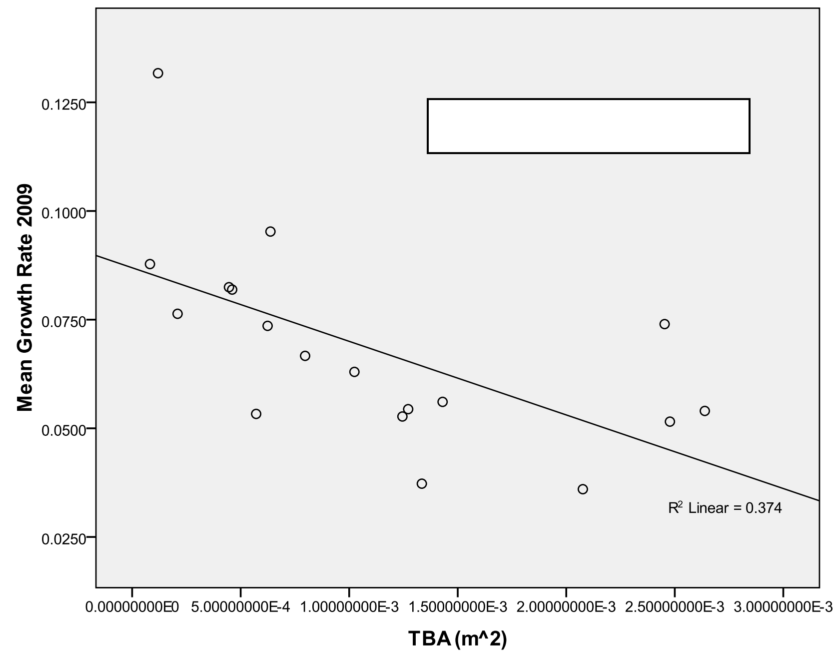

Figure 1c

Figure 1a-c: Mean Growth Rate vs. Total Basal Area in year 2007, 2008, 2009

Total basal area was found to be significantly correlated with mean growth rate in a negative, linear relationship in year 2007, 2008, and 2009 respectively.

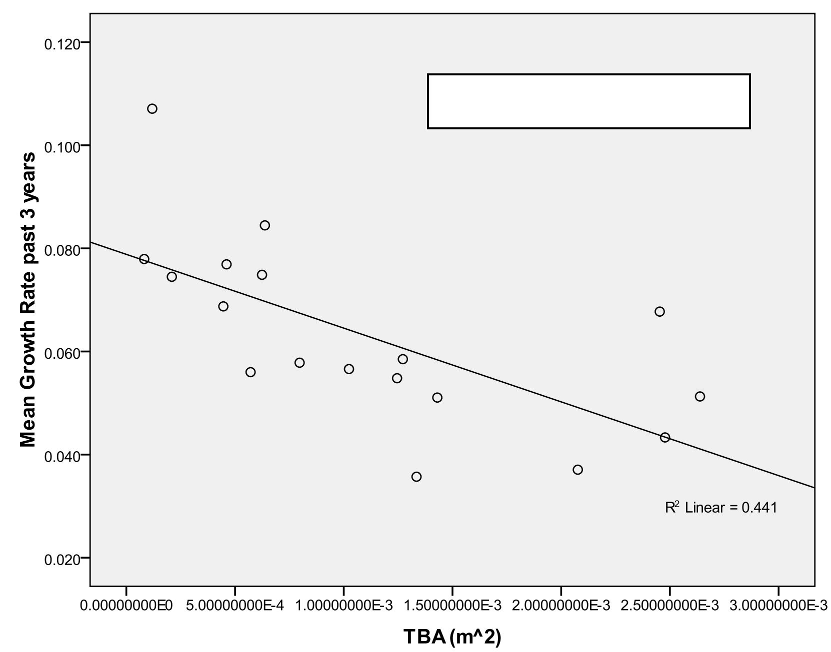

Figure 2: Mean Growth Rate in the Past Three Years vs. Total Basal Area

The strongest correlation was found between mean growth rate in the past three years and total basal area.

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