EFFECTS OF CANOPY GAPS CREATED BY HURRICANE MICHAEL ON LONGLEAF PINE AND OAK SAPLING GROWTH

By

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ACKNOWLEDGMENTS

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Climate predictions for the southeastern U.S. predict increasing intensity and frequency of hurricanes. Because windstorms influence woodland structure and fire behavior, a better understanding of the woodland dynamics that influence canopy recruitment following windstorms is needed. In this study, I investigated the response of 282 saplings from three competing upland species (*Pinus palustris, Quercus falcata, Q. margaretta*) across a secondary-growth longleaf pine woodland in southwest Georgia, United States following Hurricane Michael, to gain a better understanding of the mechanisms that influence height and radial growth. I tested the influence of sapling size, soil texture, and year individually and in combination to determine the best approximating growth model for each species. Longleaf pine was predicted to have a competitive advantage across all size classes for height growth. In the smallest size class however, both oak species were predicted to put on more radial growth when compared to longleaf pine. These results show that size of saplings at the time of a windstorm may have the greatest influence on competitive outcomes and canopy recruitment, and management intervention may be required following windstorms depending upon goals and objectives.
CHAPTER 1
INTRODUCTION

Historically, ecosystems dominated by longleaf pine (*Pinus palustris*) covered much of the southeastern United States. It is estimated that longleaf pine dominated ecosystems covered over 20 million hectares before widespread Euro-American land clearing, with an additional 15 million hectares covered by mixed-species communities containing longleaf pine (Jose et al. 2007). Among stands not harvested for timber or cleared for agricultural lands, widespread fire suppression eventually converted many to predominantly hardwood or other mixed-pine stands (Landers et al. 1995). Estimates place current longleaf woodland coverage at approximately 3% of the historical range, making them one of the most endangered ecosystems in North America and a candidate for ecosystem restoration and conservation (Oswalt et al. 2012, Noss et al. 1995). Restoration and management efforts for longleaf pine have also gained popularity due to the associated ecosystem services like increasing water yields (Qi et al. 2021, McLaughlin et al. 2013).

Longleaf pine systems frequently experience disturbances through management activities like prescribed burning and from natural events like windstorms (Keim et al. 2007, Ojha et al. 2020). Prior to widespread fire suppression and habitat fragmentation, low-intensity fires that were lightning- or human-ignited occurred every 2 – 12 years within the historic range of longleaf pine (Stambaugh et al. 2011, Delcourt and Delcourt 1998). In longleaf pine woodlands, conservation and restoration practitioners often use an ecological forestry approach where management practices attempt to mimic aspects of natural disturbances with the assumption that legacies from natural disturbances promote native biodiversity and strengthen ecosystem resilience to unplanned disturbances (Long 2009, Mitchell et al. 2006). The occurrence of frequent, low-intensity fire is critical for the survival of longleaf pine because it reduces
hardwoods and other vegetation that may outcompete the shade-intolerant seedlings and saplings (Pecot et al. 2007). Hardwood saplings such as *Quercus* spp. are susceptible to top-kill from fire at small sizes but they are able to resprout quickly due to belowground nutrients reserves (Robertson and Hmielowski 2014). Canopy disturbance from windthrow is experienced less frequently than fire across the species’ range, with significant hurricanes occurring every 100 years (Hooper and McAdie 1995). When less intense hurricanes are included, the frequency increases to a 13-year return interval on average (Keim et al. 2007). There is also widespread consensus among climate models that the number of major hurricanes is likely to increase in the future (Pielke et al. 2005, Bender et al. 2010). Woodland structure is reshaped by intense wind events through the removal of branches and uprooting or snapping of mature trees (Gardiner et al. 2016), which alters understory dynamics and resource availability through increasing light transmittance and reducing below-ground competition (McGuire et al. 2001, Pederson et al. 2008, Mitchell 2013). Canopy gap creation, by the removal of one or more mature trees, may be necessary for continued longleaf pine regeneration and canopy recruitment within managed woodlands (McGuire et al. 2001, Gagnon et al. 2003). Growth rates of longleaf pine saplings have been shown to increase in response to canopy removal (Pederson et al. 2008, Curtain et al. 2020), but the same is also true for competing oak saplings (Pecot et al. 2007). Though both species are expected to increase growth in response to increased light availability, factors such as sapling size, yearly climactic change, and soil texture may influence growth rate.

While dominated by longleaf pine in the overstory, longleaf systems are also composed of several species of oak which contribute to the high diversity within the historic longleaf pine range (Cavender-Bares et al. 2004). Many oak species serve as critical wildlife habitat for birds and insects, as well as a food source for larger mammals like white-tailed deer (*Odocoileus*
*virginianus* and fox squirrels (*Sciurius niger*) (Hanberry and Nowacki 2016, Eaton 2021). Some oak species produce leaf litter that burns poorly, and this may alter fire regimes through the process of mesophication (Nowacki and Abrams 2008, Alexander et al. 2021). Much research has been done on how to reduce oaks from longleaf ecosystems to prevent mesophication (Brockway et al. 1998, Provencher et al. 2001), but historical accounts show the presence of old-growth pyrophytic oaks (*Q. margaretta* & *Q. laevis*) in frequently burned sites dating as far back as 300 years (Knight 2004, Varner and Pederson 2004). The presence of old-growth pyrophytic oaks demonstrates their ability to resist damage and top-kill from fire at large sizes. Unlike mesophytic oaks which can disrupt fire regimes, a study by Hiers et al. 2014 suggests that low productivity on xeric sandhills prevents some oaks from producing sufficient leaf area to reduce understory light availability. Studies also show that some pyrophytic oaks may facilitate fire (Kane et al. 2008), and that leaf litter from *Q. falcata* produced flame heights and burn duration similar to that of longleaf pine litter (Fonda 2001). Two common xeric species of oaks found within the longleaf pine range include *Q. falcata*, southern red oak, and *Q. margaretta*, a white oak widely referred to as sand post oak. A study comparing oak species (Cavender-Bares et al. 2004) found that sand post oak had higher sapling bark thickness and rhizome resprouting potential compared to southern red oak, but southern red oak maintained higher asymptotic height. With increased acceptance of pyrophytic oaks as an integral part of some longleaf systems and a difference among white and red oak life history, further research into the interactions among associated species following wind disturbance and canopy recruitment initiation can help better understand post-storm dynamics in fire and wind-prone longleaf pine systems.
Though longleaf pine and associated upland oak saplings may both benefit from the change in resource availability caused by wind disturbance, the life history and growth strategies utilized by each species varies. Pecot et al. 2007 found that understory hardwoods in longleaf pine woodlands were negatively affected by belowground competition with mature trees, while longleaf seedlings were more strongly influenced by light availability and belowground competition with herbaceous plants. Studies also suggest that at high levels of canopy removal, oak saplings may respond by increasing lateral branch extension at the expense of height growth, while maintaining relatively constant radial growth (Allen and Marquis 1970, Stout and Shumway 1982). Although I expect both oaks and longleaf pine to increase growth response to canopy disturbance, there may be some threshold level of canopy openness where height growth advantage switches from the more shade-tolerant oaks to longleaf pine. This point is typically known as a crossover point irradiance (Sack and Grub 2001).

Given that hurricanes can have a large influence on longleaf pine woodland structure (Zampieri et al. 2020, Rutledge et al. 2021), and impact fire behavior (Cannon and Brewer 2013, Cannon et al. 2017) it is imperative to better understand the effects of wind disturbance on woodland recovery in a fire-prone system. Our specific objectives were: (i) determine whether hurricane damage can alter the growth responses of regenerating longleaf pines and two associated upland oak species; (ii) determine the extent to which effects on growth response vary based on factors such as tree size and soil texture; and (iii) determine the crossover point irradiance at which longleaf pine saplings obtain a competitive height growth advantage over competing oak saplings. I hypothesize that height growth of longleaf pine and two associated upland oak species to increase as gap fraction increases, but at high light levels I expect that oak height growth will be reduced relative to longleaf pine. After Hurricane Michael I expect a
reduction in oak height growth, while radial growth is expected to remain constant. On sites that experienced similar canopy removal, saplings growing in soil with greater water holding capacity (loamy sand) may exhibit a stronger growth response when compared to saplings on drier sites (sandy loam).
CHAPTER 2
MATERIALS AND METHODS

Study Site

This study took place at the Jones Center at Ichauway (Fig. 2-1), an 11,300-ha research site located in southwest Georgia, United States. The Jones Center is situated within the Lower Coastal Plain and its woodlands predominantly consist of secondary-growth *P. palustris* assemblages that maintain a humid subtropical climate (McNab and Avers 1994). A minor component of loblolly pine (*Pinus taeda* L.) and slash pine (*Pinus elliottii* Engelm.) dominated woodlands are also present (~1700 ha), and oaks (e.g., *Q. falcata* Michx., *Q. laevis* Walter, *Q. laurifolia* Michx, *Q. nigra* L., *Q. stellata* Wangenh, *Q. margaretta* Ashe, and *Q. virginana* Mill.) exist as single trees or small groups within an open pine woodland. The vast majority of forested stands at the Jones Center are managed using prescribed fire on an approximately 2-year burn rotation. Elevation ranges between 27 and 61 meters above sea level, and the landscape exhibits gently rolling hills that are typical of the Karst topography located within the Dougherty Plain. Soil orders found on the property are generally acidic and include Entisols and Ultisols that cover the Ocala limestone bedrock (Goebel et al. 2001).

Hurricane Michael made landfall on October 10th, 2018 near Mexico Beach, Florida as a category 5 hurricane. Maximum sustained wind estimates of 257 km h$^{-1}$ resulted in roughly 88% tree mortality in some longleaf pine stands near hurricane landfall (Zampieri et al. 2019). Approximately 150 km inland, hurricane impacts were sustained but less severe. The path of Hurricane Michael brought the storm within ~10 km west of the Jones Center (study site) where xeric oaks sustained higher damage from Hurricane Michael when compared to longleaf pine especially on the drier soils that dominate the site (Rutledge et al. 2021).
Sample Area Selection

To select saplings for the study, I identified sampling areas that sustained some hurricane canopy loss, contained saplings ranging between 3 – 12 m in height, were stratified across a gradient of canopy cover, and >15 m from a road. To estimate canopy cover, I used airborne lidar collected in 2018 and 2019 by NEON AOP (Kampe et al. 2010). To estimate canopy cover, I used the lidR package in R to calculate the proportion of Lidar returns in a 20 m radius moving window to provide a canopy cover index (CCI). I used the aggregate function in the raster package to generate CCI for 2018 and 2019. Ground-truth measurements for canopy cover were available thanks to a long-term monitoring program at the study site, where canopy cover was measured using the average of four densiometer readings (Holland et al. 2019). I used the ground-truth measurements to predict canopy cover from CCI at all locations, and I used the resulting canopy cover prediction for 2018 and 2019 to identify areas where canopy loss occurred. I identified a total of 34 study sites stratified across a canopy loss gradient. These contained 282 saplings, with 99 longleaf pin saplings, 92 southern red oak saplings, and 91 sand...
post oak saplings. Trees at each site were <50 m apart, and I include no more than 8 individuals per species at each site.

**Sapling and Site Measurements**

I determined the height of selected saplings by using a Celestron Regal M2 80ED Spotting Scope and an 11m Crain Fiberglass Telescoping Measuring Rod. To measure the vertical elongation of the terminal shoot I recorded heights at the bud scars for the current year (2020) and two previous years (Bigelow and Canham 2002). For each tree, I also collected a tree core sample taken 15 cm above root collar. Tree cores were dried at 70º C for 24 hours and then glued to a mounting board. Tree cores were then sanded with progressively finer grit then ring widths were measured to 0.001 mm accuracy using a Velmex movable stage micrometer and MeasureJ2X software. For each sapling, I also obtained diameter at breast height (DBH), and location using a GPS with sub-meter accuracy (Trimble Nomad GPS). GPS location was used with the United States Department of Agriculture Web Soil Survey to determine soil texture at each site.

**Statistical Modeling**

To model how changes in canopy cover and abiotic conditions effected height growth and radial growth among the sampled trees, I used a maximum likelihood approach where I defined each growth rate as a function of gap fraction \((1 – CCI)\), tree size (height or radius depending on the response variable), year (to capture year-to-year climatic variability including Hurricane Michael), and soil texture (sandy loam or loamy sand). For each response variable (height or diameter growth) I first defined each growth rate as a function of gap fraction and size
and then compared three functions for the relationship between growth rate and gap fraction (linear, exponential, or saturating). The equation for the linear model with height covariate was

\[
\text{height growth} = (a + (b \times G)) \times ht^f
\]

where \(G = \text{Gap fraction (\%)}, \ ht = \text{tree height (m)}, \) and \(f = \text{size effect, } a = \text{slope, } b = \text{y-intercept.}\)

The equation for the saturating Michaelis-Menten model with height covariate was

\[
\text{height growth} = \left( \frac{a \times (G)}{\left( \frac{a}{s} \right) + (G)} \right) \times ht^f
\]

where \(s = \text{saturation point.}\) The equation for the exponential model with height covariate was

\[
\text{height growth} = a^{(b \times (G) \times ht^f)}
\]

I compared the growth rate predictions from size and gap fraction using sample size corrected Akaike’s information criterion (\(AIC_c\)) to select the best model. Next, I compared predictions of these size and gap fraction only models to models that also included additional terms for year or soil texture, or both effects. The equation for the linear model with the height and soil covariates was

\[
\text{height growth} = (a + (b \times G)) \times ht^f \times g[\text{txt}]
\]
Where $g =$ coefficient for soil effect and $txt = 1$ or $2$ depending upon soil texture. The equation for the linear model with the height and year covariates was

$$height\ growth = (a[yr] + (b[yr] * G)) * ht^f$$

Where $yr$ represents either 2018, 2019, or 2020. The equation for the linear model with the height, year and soil covariates was

$$height\ growth = (a[yr] + (b[yr] * G)) * ht^f * g[txt]$$

I also included an intercept-only model for each growth response as a null model for comparison. I compared each model using $\Delta$, the difference between the $AICc$ of the model in question and the best approximating model. This process was repeated for diameter growth, substituting the size metric to diameter growth.
CHAPTER 3
RESULTS

Canopy cover from ground plots was correlated to lidar-derived CCI (R = 0.1739);

\[ \text{Canopy cover} = 0.313 + CCI \times 0.8627 \]. Among the saplings in the study, diameter at breast height was 5.8 (±2.24) cm for longleaf pine, 5.5 (±2.45) cm for southern red oak and 6.1 (±2.80) cm for sand post oak. Average height was 6.5 (±2.18) m for longleaf pine, 5.5 (±1.87) m for southern red oak and 5.7 (±1.71) m for sand post oak. Total tree height increased with DBH for all species, but longleaf pine generally had a larger height for a given diameter compared to sand post oak, especially for larger diameter trees. Longleaf pine was also taller for a given diameter relative to southern red oak, except for larger diameter trees. (Figure 3-1).

![Graph showing relationship between sapling height and diameter at breast height (DBH) for longleaf pine (Pinus palustris, n = 99) and two associated upland oak species (Quercus falcata & Q. margaretta, n= 92 & n=91) in second-growth longleaf pine woodland in Southwest Georgia, USA.](image-url)
Height Growth

Likelihood analysis indicated that the Michaelis-Menten model that included size, year, and soil effects was the best approximating model for height growth of longleaf pine. However, the simpler Michaelis-Menten model that only included size and year effects was used for inference because it had a $\Delta_i$ within 2 units and contained fewer parameters than the Michaelis-Menten model with size, year, and soil effects (Table 2-1). For both oak species, the Michaelis-Menten model with size and year effects was the best approximating model (Table 2-1). In 2020, height growth rate was greater for a given level of gap fraction than previous years, especially for longleaf pine (Figure 3-2). Predicted height growth for longleaf pine is consistently higher at all light levels when compared to the two competing oak species across all years. The white oak species ($Q. margaretta$) shows a predicted height growth advantage over the red oak species ($Q. falcata$) at low light levels, but this advantage quickly diminishes as gap fraction decreases.

Radial Growth

The model that included a linear effect of gap fraction and a size effect was the best approximating model for longleaf pine (Table 3-2), while the model that included a linear effect of gap fraction with size and year effects was the best approximating model for southern red oak (Table 3-2). The linear model with size effect was determined to be the best approximating model for sand post oak radial growth (Table 3-2). Oaks in the smallest size class are predicted to put on more radial growth when compared to longleaf pine, but radial growth of pines exceeds the oaks among larger size classes (Figure 3-3C). Only southern red oak had a best model that
included a year effect, with significantly decreased radial growth rates appearing 1 year after Hurricane Michael.

Table 3-1. Statistics for models of height growth for *P. palustris*, *Q. falcata*, and *Q. margaretta* in second-growth longleaf pine woodlands in Georgia, USA; the best approximating model (bold) is the Michaelis-Menten model with size, year, and soil effects.

<table>
<thead>
<tr>
<th>Species</th>
<th>Model</th>
<th>$AIC_C$</th>
<th>$\Delta i$</th>
<th>$R^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Pinus palustris</em></td>
<td><em>Null model</em></td>
<td>129.74</td>
<td>143.28</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>Linear</td>
<td>130.50</td>
<td>144.04</td>
<td>0.002</td>
</tr>
<tr>
<td></td>
<td><em>Linear × size</em></td>
<td>84.83</td>
<td>98.37</td>
<td>0.159</td>
</tr>
<tr>
<td></td>
<td><em>MM × size</em></td>
<td>86.68</td>
<td>100.22</td>
<td>0.156</td>
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<tr>
<td></td>
<td><em>Exp × size</em></td>
<td>93.50</td>
<td>107.04</td>
<td>0.135</td>
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<tr>
<td></td>
<td><em>Linear × size × soil</em></td>
<td>79.94</td>
<td>93.48</td>
<td>0.197</td>
</tr>
<tr>
<td></td>
<td><em>Linear × size × year</em></td>
<td>-9.40</td>
<td>4.14</td>
<td>0.406</td>
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<td><em>Linear × size × year × soil</em></td>
<td>-11.24</td>
<td>2.30</td>
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<td><em>MM × size × year</em></td>
<td><strong>-12.30</strong></td>
<td><strong>1.24</strong></td>
<td><strong>0.405</strong></td>
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<td><em>MM × size × soil</em></td>
<td>82.51</td>
<td>96.05</td>
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<tr>
<td></td>
<td><em>MM × size × year × soil</em></td>
<td>-13.54</td>
<td>0.00</td>
<td>0.42</td>
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<tr>
<td><em>Quercus falcata</em></td>
<td><em>Null model</em></td>
<td>-244.93</td>
<td>26.46</td>
<td>&lt; 0.001</td>
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<td></td>
<td>Linear</td>
<td>-245.37</td>
<td>26.02</td>
<td>0.012</td>
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<td></td>
<td><em>Linear × size</em></td>
<td>-259.83</td>
<td>11.55</td>
<td>0.069</td>
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<td></td>
<td><em>MM × size</em></td>
<td>-263.84</td>
<td>7.55</td>
<td>0.079</td>
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<td></td>
<td><em>Exp × size</em></td>
<td>-254.66</td>
<td>16.72</td>
<td>0.081</td>
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<td></td>
<td><em>MM × size × year</em></td>
<td><strong>-271.38</strong></td>
<td><strong>0.00</strong></td>
<td><strong>0.116</strong></td>
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<td><em>MM × size × soil</em></td>
<td>-261.04</td>
<td>10.34</td>
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<td><em>MM × size × year × soil</em></td>
<td>-268.35</td>
<td>3.03</td>
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<tr>
<td><em>Quercus margaretta</em></td>
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<td>-420.31</td>
<td>37.76</td>
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<tr>
<td></td>
<td>Linear</td>
<td>-418.90</td>
<td>39.17</td>
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<td></td>
<td><em>Linear × size</em></td>
<td>-444.60</td>
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<td><em>MM × size</em></td>
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<td>13.50</td>
<td>0.084</td>
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<td><em>Exp × size</em></td>
<td>-424.56</td>
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<td>0.033</td>
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<td><em>Linear × size × soil</em></td>
<td>-442.13</td>
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<td><em>Linear × size × year</em></td>
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<td>4.54</td>
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<td><em>MM × size × year</em></td>
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<td><strong>0.00</strong></td>
<td><strong>0.135</strong></td>
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<td>15.86</td>
<td>0.089</td>
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<tr>
<td></td>
<td><em>MM × size × year × soil</em></td>
<td>-455.37</td>
<td>2.69</td>
<td>0.139</td>
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Table 3-2. Statistics for models of radial growth for *P. palustris, Q. falcata,* and *Q. margaretta* in second-growth longleaf pine woodland in Georgia, USA; the best approximating model (bold) is the linear model with size effect.

<table>
<thead>
<tr>
<th>Species</th>
<th>Model</th>
<th>AIC&lt;sub&gt;c&lt;/sub&gt;</th>
<th>Δ&lt;sub&gt;i&lt;/sub&gt;</th>
<th>R&lt;sup&gt;2&lt;/sup&gt;</th>
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<td><em>Pinus palustris</em></td>
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<td>725.92</td>
<td>15.79</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td></td>
<td>Linear</td>
<td>720.63</td>
<td>10.50</td>
<td>0.022</td>
</tr>
<tr>
<td></td>
<td><strong>Linear × size</strong></td>
<td><strong>710.13</strong></td>
<td><strong>0.00</strong></td>
<td><strong>0.061</strong></td>
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<tr>
<td></td>
<td>MM × size</td>
<td>745.16</td>
<td>35.03</td>
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<td>Exp × size</td>
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Figure 3-2. Yearly predicted height growth for three size categories of upland tree species in second-growth longleaf pine woodland in southwest Georgia, USA.
Figure 3-3. Predicted radial growth for three size categories of three upland tree species in second-growth longleaf pine woodland in southwest Georgia, USA. Annual growth differences were only significant for *Q. falcata*, with reduced radial growth occurring 1 year after Hurricane Michael.
Hurricanes are common in Gulf Coastal woodlands, and have enormous destructive force, and potentially re-organize tree communities through altering resource availability (Paudel and Battaglia 2021). Canopy removal may increase light availability for seedlings and saplings, but other factors such as soil texture and size may also have the capacity to influence competitive outcomes (Mitchell 2013). In mixed oak-longleaf woodlands, increased light availability may give longleaf pine a competitive advantage through increased height growth. Studies also show that wind disturbance may cause succession to accelerate, thus releasing shade-tolerant saplings that established prior to the disturbance (Holzmueller et al. 2012, White et al. 2015).

The size of saplings at the time of release event has strong influence on competitive outcomes. These results suggest that oak height growth is minimal after a hurricane, but radial growth rate for southern red oak significantly decreased one year after Hurricane Michael. At low light levels, southern red oak is predicted to have the highest radial growth compared to the two other species. Though for height growth the opposite is true, with sand post oak consistently outperforming southern red oak at low light levels.

I did not detect a crossover point irradiance (CPI) for height growth of longleaf pine and the two competing xeric oak species. Radial growth, however, does exhibit a CPI between longleaf pine and sand post oak within the middle size class, and with southern red oak within the largest size class. Height growth remained constant for southern red oak at low light levels while radial growth increased, supporting our hypothesis that oaks may reduce height growth but not radial growth following a canopy opening event. It is possible that the effects of resource availability may take longer than two growing seasons to become apparent. A similar study suggest that Pinus spp. can experience a decline in radial growth the same year as an extreme
storm as well as the 3 following years (Fernandes et al. 2018). To obtain a better understanding of the woodland reorganization following a windstorm, a more long-term study would be required.

The effects of windstorms in ecosystems that experience frequent fire may depend upon the time elapsed between the disturbance and fire. Canopy removal may allow oak saplings to quickly grow to a size that is able to withstand surface fires. Wind disturbance influences fire behavior by altering surface fuel loads and creating microclimates with increased solar input that may increase probability and intensity of fire (Cannon et al. 2019). Within old-growth systems, it is likely that the largest trees will snap or be uprooted due to windthrow (Sharma et al. 2021). Along with altering canopy openness, this will likely increase the heterogeneity of fire intensity due to the highly localized accumulation of fine fuels where the crown falls. Soil moisture may also influence damage severity depending upon species, with longleaf generally being more resistant to wind-induced mortality when compared to other southern pines, especially in wetter soils (Rutledge et al. 2021).

**Management Implications**

If management goals are focused on biodiversity conservation or restoration of longleaf system, fire may be sufficient to maintain desired woodland cover. For this management goal, periodic hurricanes may serve a role in maintaining continuous woodland regeneration and canopy recruitment. If regeneration is advanced, it is likely that frequent fire will maintain the current species composition. When fire is excluded from the landscape following a windstorm, both longleaf pine and oak sapling density have been shown to increase in response to wind-disturbance when compared to undisturbed stands (Kleinman and Hart 2017). Though wind disturbance may lead to stands accumulating hazardous amounts of fuel loads, removing fire
from a frequently burned stand may be a disturbance itself (Roberts 2004). Land managers whose main focus is timber production may need to implement additional treatment (mechanical/herbicide) to prevent pines from being outcompeted, depending upon the size of the saplings at the time of disturbance. Though longleaf pine has been shown to recruit to canopy status following multiple suppression and release events (Curtin et al. 2020).

Along with increased windstorm frequency and severity, climate change is predicted to influence temperature and rainfall (Bender et al. 2010). Longleaf pine has been shown to increase radial growth in response to hotter and drier climactic shifts (Pederson et al. 2008), suggesting that the species may respond positively to certain aspects of climate change. Conversely, oaks have been shown to respond negatively to decreased soil moisture (Leblanc and Stahle 2015), suggesting that climate change may reduce competition from oaks in longleaf pine woodlands.
REFERENCES


Cody Pope received his Bachelor of Science in Environmental Biology from the University of Southern Mississippi. As an undergraduate, he completed an Honor’s Thesis while working in Dr. Kuehn’s Microbial Ecology Laboratory.