GROWTH RESPONSE OF MATURE LONGLEAF PINE TO DROUGHT AND THINNING AT THE HARRISON EXPERIMENTAL FOREST IN SOUTH MISSISSIPPI

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ABSTRACT

We explored the diameter growth of longleaf pine (*Pinus palustris*) planted in 1961, during the years following disturbances from Hurricane Katrina (2005) and thinning (2011) at the Harrison Experimental Forest in southern Mississippi. Winds from Hurricane Katrina destroyed 7 percent of the longleaf pine and damaged much more, while the thinning was variable based on existing density, with 29 percent of trees being removed. In April 2017, a total of 180 trees were sampled with an increment borer and analyzed to quantify basal area increment (BAI). After Hurricane Katrina impacted the site in 2005, BAI declined an average of 23 percent during the next 6 years. Immediately after thinning, growth markedly increased in 2012 (50 percent) and 2013 (30 percent). Without any other context, the interannual variation in BAI could be interpreted as being driven primarily by disturbance. However, the site had experienced prolonged drought during the years following Hurricane Katrina which was eventually alleviated in 2012. Using a suite of climate variables (monthly precipitation, air temperature, solar radiation, and vapor pressure deficit), we found that 79 percent of the annual variation in BAI could be explained by the amount of precipitation during the growing season (partial $R^2 = 0.59$) and warm winter nights in January (partial $R^2 = 0.05$) and February (partial $R^2 = 0.15$). The 50-year-old longleaf pine trees were unresponsive to thinning, and variation in interannual growth rates was primarily dependent on climate. It seems the trees of that age have limited ability to exploit additional light, moisture, and nutrient resources. If the goal of thinning is to increase the growth rate of residual trees, it should be implemented at an earlier age or perhaps be combined with fertilization.

INTRODUCTION

Longleaf pine (*Pinus palustris*) is a long-lived tree that is well suited to extended rotations in the Gulf Coast, where it is grown for commercial purposes or to create wildlife habitat. Thinning is often employed in young plantations to remove undesirable trees and increase resource availability (i.e., soil nutrients and water and access to light) to residual trees. When timed appropriately, thinning can maximize tree growth and improve stem quality. Early studies with longleaf pine focused on thinning dense natural regeneration beginning at age 15 (Gaines 1951), and positive diameter growth responses were observed from thinning as late as 37 years (Farrar 1968). These early studies recommended frequent thinning (every 5 years) on average sites, retaining no more than 14 $m^2 ha^{-1}$ (60 square feet per acre) of residual basal area (BA) to maximize volume growth (Farrar 1968). In an effort to more broadly restore longleaf pine across the landscape, nursery stock was deployed in the form of plantations, even though the principal benefits of biodiversity, disturbance resistance, and natural regeneration are derived through uneven-aged management, frequent burning, and maintenance of relatively low canopy tree BA (Mitchell and others 2006). The first commercial thinning of planted stock typically occurs between 13 and 18 years depending on site productivity (Nebeker and others 1985). However, many overstocked plantations exist that were planted at low density and never thinned. Little is known about the response of these overstocked mature trees to natural and silvicultural disturbances. Exposure to decades of intraspecific competition without thinning may lead to trees with narrow crowns, low live crown length, and elevated height-to-diameter at breast height ratios that make them more susceptible to breakage (Harrington 2020).

Longleaf pine is known to be resistant to blowdowns and breakage from hurricanes that occur frequently in the Southern United States (Johnsen and others 2009). Prior to settlement and widespread destruction from conversion to farmland, land areas along the Coastal Plain and Piedmont favored longleaf pine ecosystems due to their resistance to wind damage from hurricanes coupled with adaptation to periodic fires (Rutledge and others 2021). There are several recent reports that categorize and quantify the wind firmness and resistance to wind damage among southern tree species (Bigelow and others 2020, Johnsen and others 2009, Rutledge and others 2021, Zampieri and others 2020), though

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lingering effects of damage in subsequent years have been less studied. Hurricanes topple and break trees, akin to a chaotic thinning, but what cost to future growth results from branch, foliage, and partial crown loss?

The primary purpose of this study was to evaluate whether mature longleaf pines at the Harrison Experimental Forest near Saucier, MS, exhibit a growth response to thinning. The story is complicated by tree mortality due to intraspecific competition and damage from hurricanes that reduced the initial 3-m x 3-m spacing (1,075 trees/ha [TPH]). While the site was planted at low density (1,075 TPH), it was only thinned after 50 years of growth, which is a departure from standard silvicultural practices. We explored diameter growth at both the tree and plot level using increment cores in the years following disturbances from Hurricane Katrina (2005) and thinning (2011).

MATERIALS AND METHODS

Site

The study was conducted at the Harrison Experimental Forest near Saucier, MS, on a large experimental planting known as "section 36" and the "species by culture experiment" (30.65° N, 89.04° W, elevation 50 m), which examined the effects of intensive silviculture on the growth of longleaf, loblolly (*P. taeda*), and slash (*P. elliottii*) pines (Schmidtling 1973). The soils are highly variable and classified as the Poarch and Saucier series (coarse loamy, siliceous, semiactive, thermic Plinthic Paleudults) and the Saucier-Susquehanna complex, which are well drained with slopes ranging from 1 to 4 percent. The soil is characterized as being phosphorus deficient, with relatively low carbon and nitrogen contents, and consequently has no history of agriculture (Butnor and others 2012). The plantation was heavily damaged by Hurricane Katrina in 2005 and mortality varied by pine species: 7 percent of longleaf pine, 14 percent of slash pine, and 26 percent of loblolly pine (Johnsen and others 2009). A major harvest of 12 gaps and thinning of the remaining plots were implemented in 2011.

Experimental Design and Measurements

The original experiment was composed of 120 plots: 4 blocks, 3 species (longleaf, slash, loblolly pine), and 10 treatments planted with 3-m x 3-m spacing (Schmidtling 1973). During the 2011 harvest, 12 gaps (55 x 55 m) were created by removing trees in 4 contiguous blocks, reducing the number of plots to 72. Of the remaining longleaf pine plots, 22 were deemed to be suited for continued study. The original 100-tree measurement plots were collapsed to 10-m-radius plots from plot center. In 2006, they ranged in stand density from 95 to 637 TPH and BA from 8 to 39 $m^2 ha^{-1}$. The thinning was conducted by a contractor, using a BA target of 14 $m^2 ha^{-1}$ for one-half of the plots and 23 $m^2 ha^{-1}$ for the other half. In 2017, 180 trees were cored from two directions (south and north) and the annual increment or radius was measured using ImageJ version 1.54h software after being scanned on an Epson® Expression 11000XL scanner (fig. 1). Of the 180 trees, 116 were from the 23 $m^2 ha^{-1}$ thinned plots and 64 from the 14 $m^2 ha^{-1}$ plots. Annual area growth per tree (cm^2) or basal area increment (BAI) was calculated, summed for each plot, and also expressed as BA in $m^2 ha^{-1}$. As there were no inventories

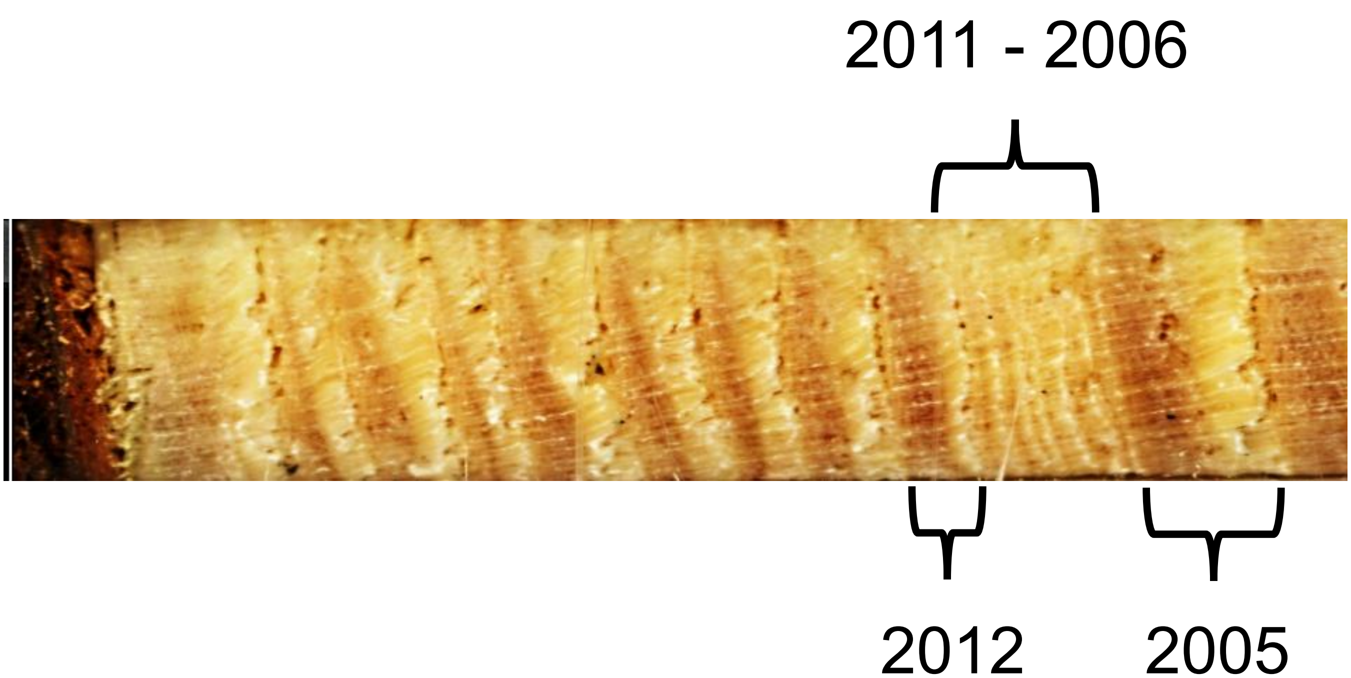

Figure 1—Representative core showing large radial growth in 2005, followed by 6 years of stagnant growth following Hurricane Katrina. After thinning in 2011, radial growth increased dramatically (USDA Forest Service photo by Robert J. Eaton).

prior to the harvest and increment data were only available for live residual trees, the growth rate of residual trees in each plot was determined for years 2006 through 2011 and applied to the trees that were harvested in 2011. By "growing out" the trees since the inventory, an accurate assessment of the BA harvested was computed. Since the entire plantation was impacted by thinning, a nearby longleaf pine plantation with the same establishment year and similar hurricane exposure with no history of thinning was used as a control. The site is described in detail by Snyder and Namkoong (1978) and commonly referred to as the "longleaf pine diallel study" at the Harrison Experiment Forest. We randomly selected 6 plots that varied in BA from 12.7 to 29.0 $m^2 ha^{-1}$ for a total of 51 trees and 2 cores per tree were collected in January 2021. When necessary to predict bark thickness to compute stand-level BA, an equation by Cao and Pepper (1986) was applied. Daily estimates of climate variables (maximum [Tmax] and minimum [Tmin] air temperature, precipitation, solar radiation, and vapor pressure) were accessed via DAYMET (https://daymet.ornl.gov/) for years 1998 through 2016 and monthly means were calculated. Growing season precipitation was computed for each year as the sum of rainfall from March through October. The data were analyzed using a completely randomized plot design, utilizing correlation, linear regression, and stepwise linear regression with SAS 9.14 (SAS Institute 2015).

RESULTS

Hurricane Katrina impacted the Harrison Experimental Forest, in late August 2005, killing 7 percent of the longleaf pine in the section 36 study (Johnsen and others 2009). By comparison, the 2011 thinning operation removed 29 percent of the longleaf pine that survived Hurricane Katrina. After Hurricane Katrina, BAI declined an average of 23 percent during the next 6 years (fig. 2). Immediately after thinning, growth markedly increased in 2012 (50 percent) and 2013 (30 percent). The thinning removed four times as many trees as the hurricane and large increases in growth were observed the following year (fig. 2). Without any other context, the interannual variation in BAI could be interpreted as being driven primarily by disturbance. Hurricane Katrina only killed 7 percent of trees in 2005 but likely caused loss of foliage and branches that compromised the photosynthetic machinery of the stand resulting in suppressed growth for years. However, it is readily apparent that precipitation and BAI are closely related, and the alleviation of drought in 2012 was related to the uptick in individual tree growth (figs. 3 and 4). When the full suite of monthly climate variables was

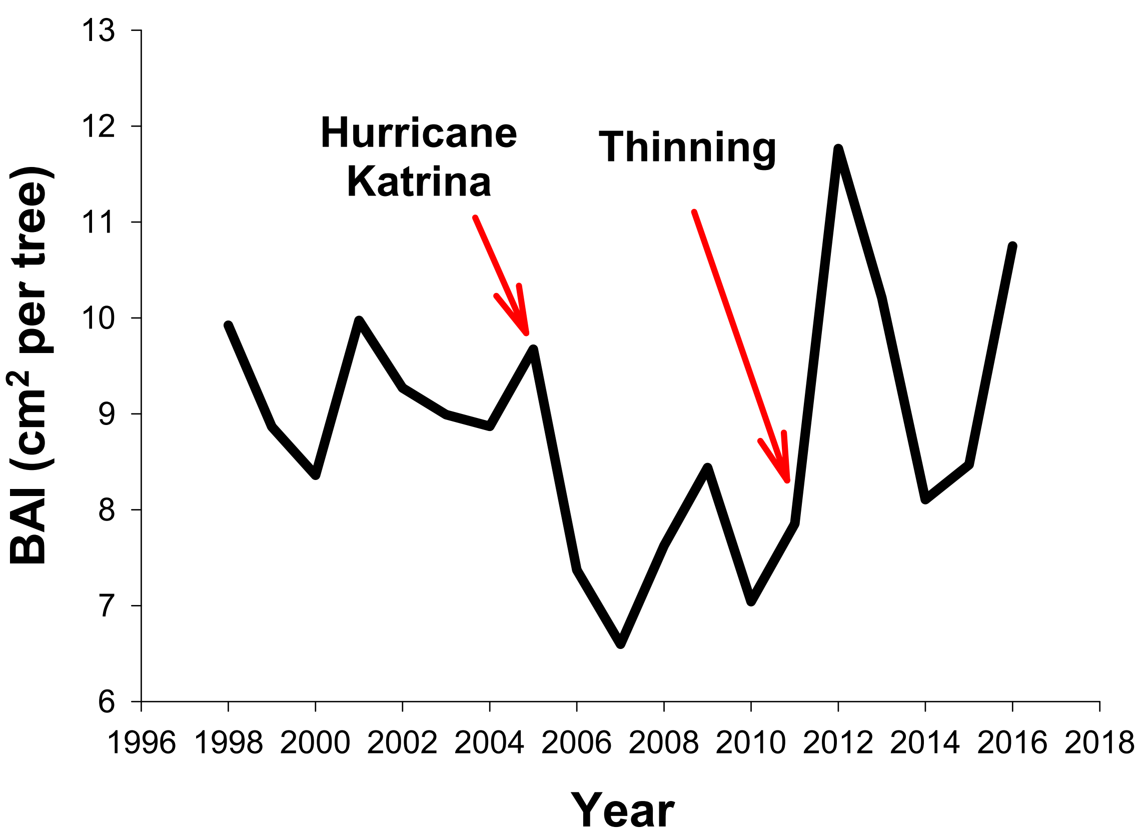

Figure 2—Mean basal area index (BAI) (per tree) of 180 longleaf pine trees located in the section 36 study at the Harrison Experimental Forest for years 1998 through 2016. Arrows denote major disturbance events from Hurricane Katrina (2005) and thinning (2011).

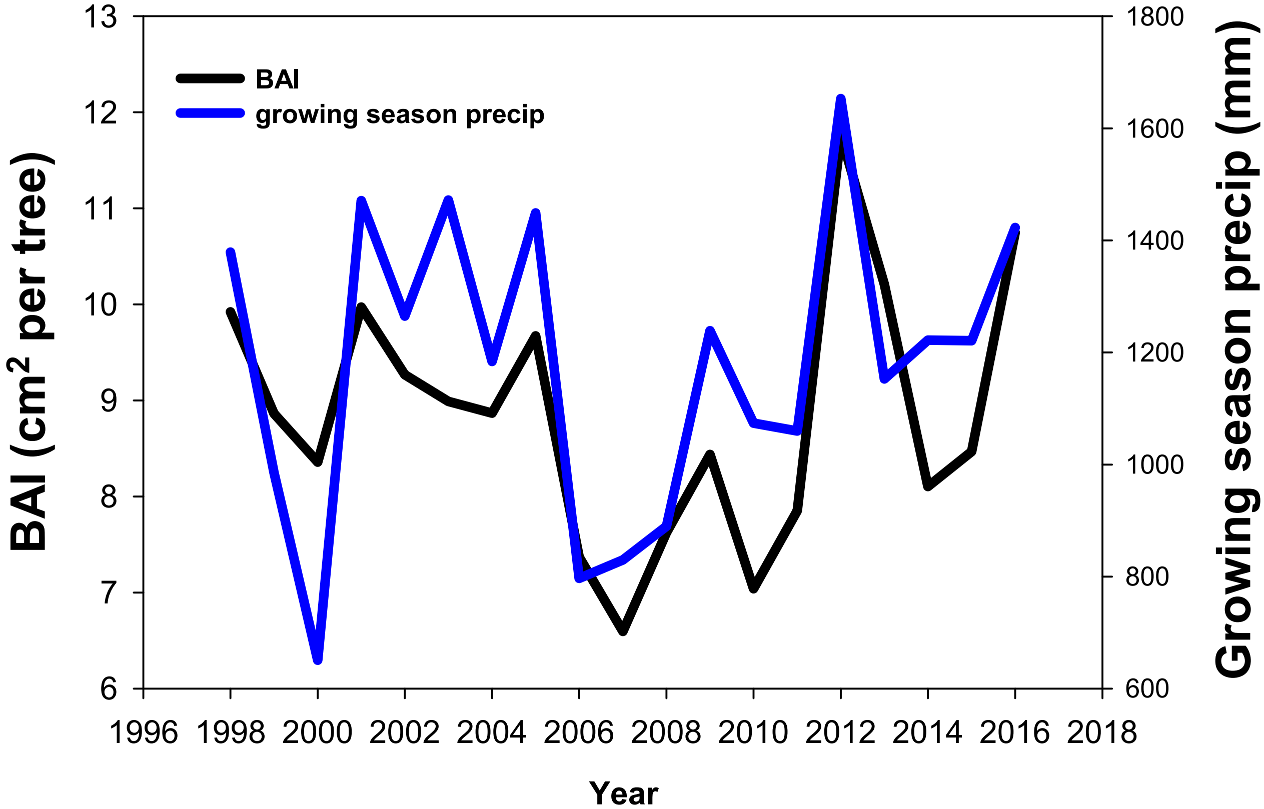

Figure 3—Overlay of basal area index (BAI) (per tree) and growing season precipitation (March through October) for years 1998 through 2016.

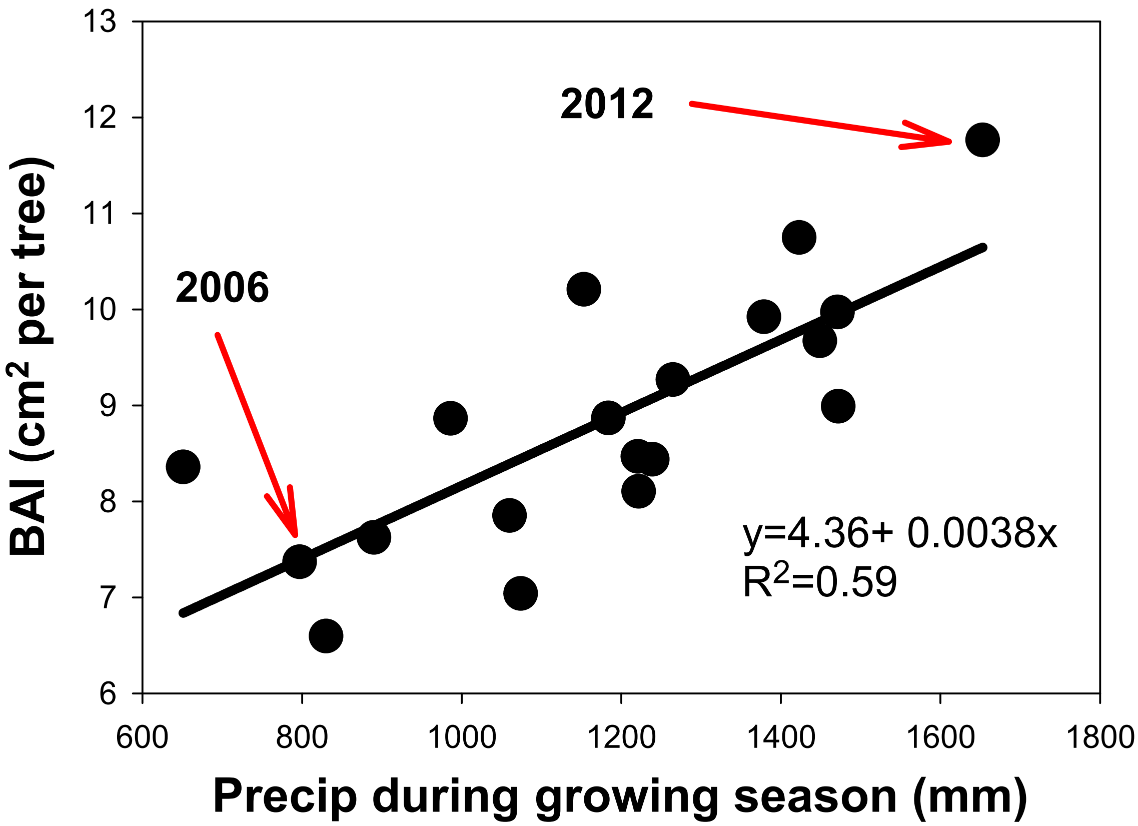

Figure 4—Linear regression of mean basal area increment (BAI) (per tree) and growing season precipitation (March through October) for years 1998 through 2016. Arrows denote the year after major disturbance events: hurricane impact (2006) and thinning (2012).

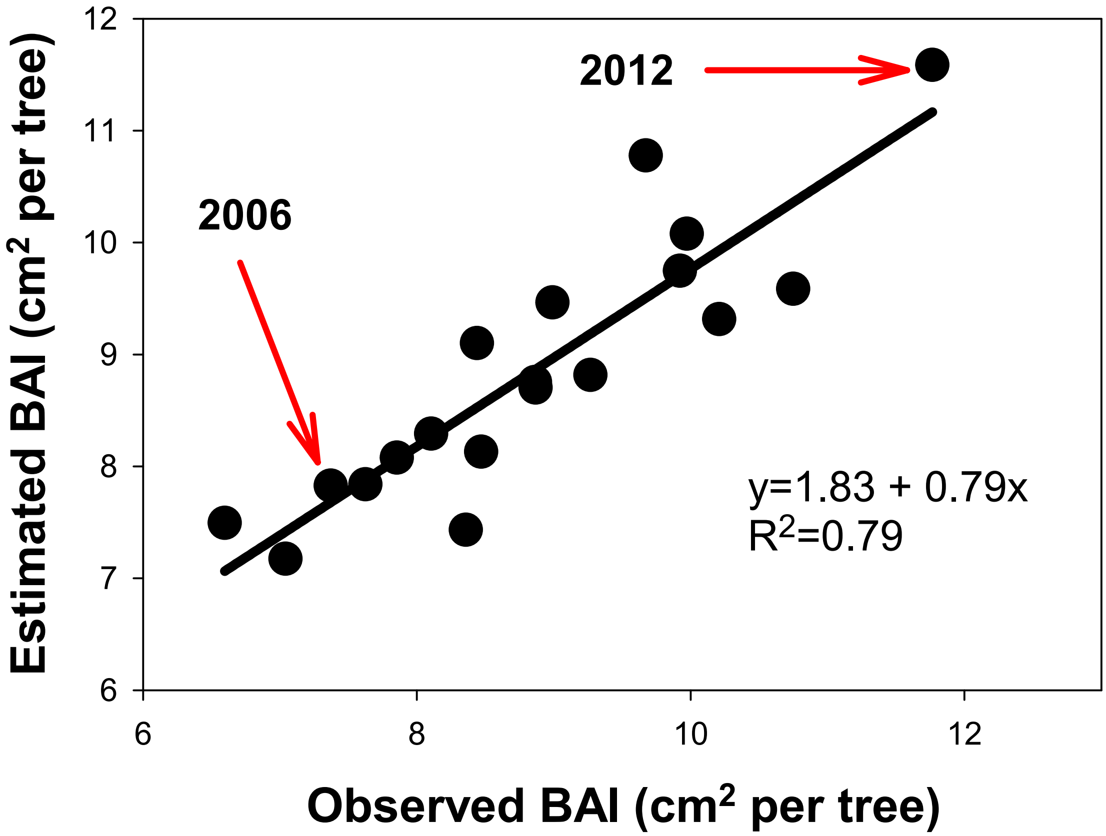

Figure 5—Multivariate model of basal area index (BAI) [equation (1)] versus observed BAI.

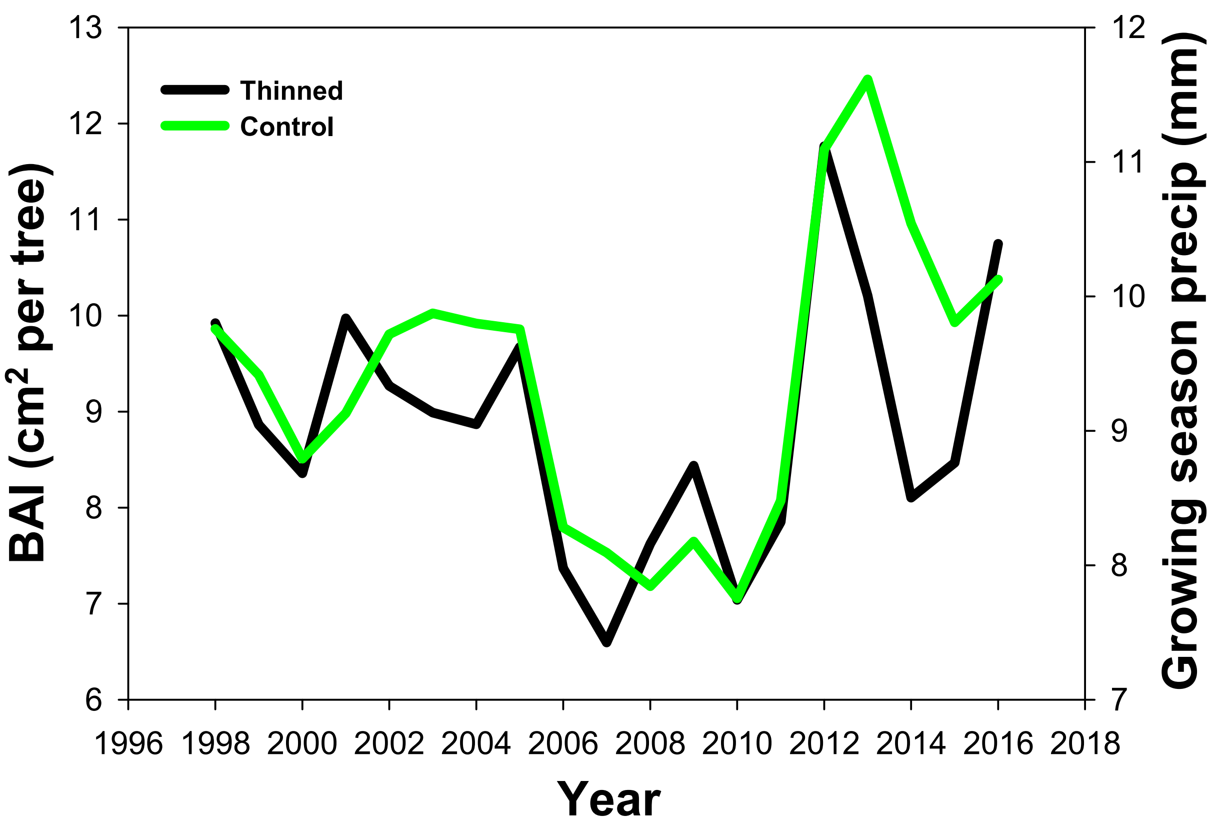

Figure 6—Mean basal area index (BAI) (per tree) for thinned and control plots for years 1998 through 2016.

considered, warm minimum temperatures in January and February were also found to contribute to BAI. The combined model [equation (1)] explained 79 percent of the variation in BAI (partial R^2s: growing season precipitation = 0.59; January Tmin = 0.05, February Tmin = 0.15). Viewed through this analysis, warm late winter nights and plentiful rainfall during the growing season appear to be the main drivers of BAI variation in mature longleaf pines (fig. 5).

*Annual BAI = 2.94289 + 0.15326*January Tmin (°C) + 0.18889* February Tmin (°C) + 0.00358*growing season precipitation (mm)* (1)

Both thinned and control plots follow similar growth patterns, which is closely linked to the amount of rainfall during the growing season (fig. 6). Prior to thinning, the BAIs of control and thinned plots are highly correlated (R^2 = 0.70), but in the years after thinning, the treated plots lagged in growth (R^2 = 0.21). To more closely examine if there was any thinning response, we compared the amount of BA harvested and the residual BA to the change in BAI before (2011) and after the harvest (2012). The same analysis was repeated comparing the BAI in 2011 with the mean of the next 5 years. There were no significant effects of the amount of BA harvested or residual BA on growth, as gauged by BAI either in the following year (data not shown) or the mean of the next 5 years (fig. 7).

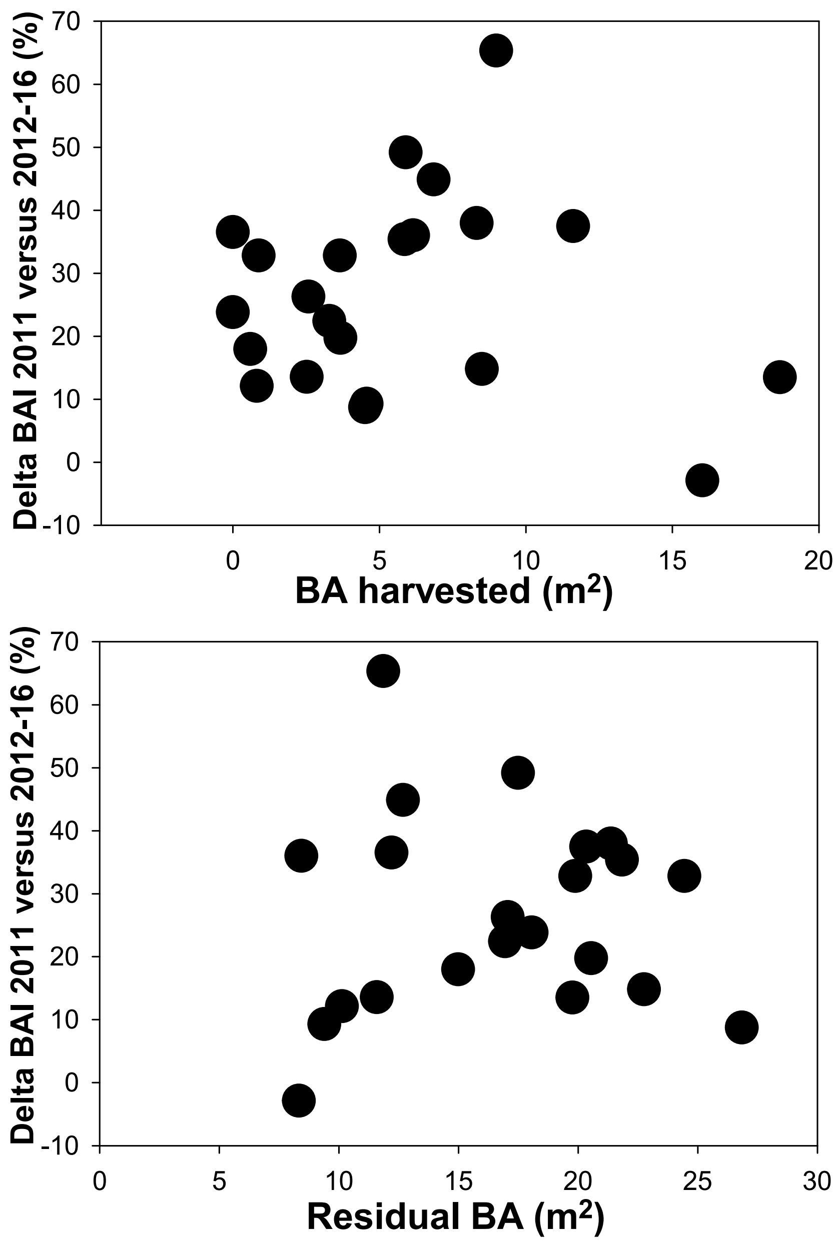

Figure 7—Effect of basal area removal and residual basal area on basal area index (BAI).

DISCUSSION

While the intent of this study was to examine the growth response of mature longleaf pine to disturbance either from natural events or harvesting, it served to quantify the sensitivity of growth to annual variation in temperature and rainfall. Longleaf pine can persist in very well drained sandy soils, but growth is highly sensitive to moisture availability during the growing season. Under extreme drought conditions, longleaf pine is able to exert stomatal control over water loss and cease transpiration for extended periods (Samuelson and others 2019). This affords a degree of climate resilience, where trees may persist until drought conditions are alleviated. Curtailing transpiration sharply limits photosynthesis, leading to declines in growth. In a precipitation exclusion experiment conducted in a 13-year-old plantation, Samuelson and others (2019) found that a 40-percent reduction in throughfall led to a 21-percent reduction in longleaf pine volume growth during three growing seasons with little mortality. By way of comparison with the present study (50-year-old longleaf pine), growing season precipitation in 1999 was 40 percent lower than 2012 and BAI was 25 percent lower. Obviously, there are multiyear effects of drought that need consideration, but the scale of drought sensitivity seems commensurate across these disparate age classes.

We did not observe any effects of BA removed or residual BA on BAI during the 5 years after harvesting. This differs from prior longleaf pine studies that aimed to keep growth rates near maximum, by employing multiple thinnings at earlier stand ages (Farrar 1968, Gaines 1951). Younger trees in the exponential growth phase have greater opportunity to take advantage of additional light resources. Sword Sayer and others (2004) found that loblolly pines that were thinned at age 7 and 14 years developed greater live crown length and had increased BA relative to control stands. It seems likely that canopy architecture and the development of tall trees with narrow crowns (Harrington 2020) limits the ability to refit the photosynthetic apparatus of the tree to take advantage of more light at age 50. Observing the plantation 5 years post-harvest, the holes in the canopy created by thinning are largely unchanged and the crowns of residual trees do not appear to have enhanced growth adjacent to gaps. The relatively nutrient-poor condition of the soil, especially phosphorus (Butnor and others 2012, 2020), likely mutes any potential enhancement in leaf area and growth (Sword Sayer and others 2004). Although somewhat complicated by the onset of extended, multiyear drought after Hurricane Katrina in 2005, there was little effect of this disturbance on growth of residual trees. This is not surprising when the extent of BA removed by the hurricane was 7 percent and the thinning was 29 percent.

CONCLUSIONS

The 50-year-old longleaf pine trees were unresponsive to thinning, and variation in interannual growth rates was primarily dependent on weather. Thinning likely has positive effects on biodiversity, wildlife, understory development, and regeneration, but it seems the mature trees have limited ability to exploit additional light, moisture, and nutrient resources for accelerated growth. If the goal of thinning is to increase the growth rate of residual trees, it should come at an earlier age or perhaps be combined with fertilization.

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