Drought effects on forest regeneration in the Southeast - a regional analysis based on FHM/FIA data

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Introduction

Across the southeastern United States, extensive forest areas have experienced several moderate to severe droughts over the past three decades (e.g., 1986-1989, 1998-2001, and 2005-2006) as indicated by PDSI (Palmer Drought Severity Index) (Palmer 1965; Klos et al. 2009). Many climate change scenarios have predicted the continued increase of drought frequency and intensity across the southeastern United States. Therefore, understanding how drought affects forest regeneration on different sites under varying stand conditions is essential to successfully mitigate negative impacts of drought on the sustainability of forest ecosystems. In this study, we used FHM (Forest Health and Monitoring) data to explore the effects of different drought severities on forest regeneration at a regional scale.

Objectives

Our objective was to investigate changes in sapling size trees across the southeastern United States under various drought conditions using 1991-2005 FHM plot data from Alabama, Georgia, and Virginia. Specially, we examined how drought severity influenced the rates of annual growth, mortality, and recruitment using PDSI as an indicator of drought severity. Drought effects were examined for three special groups (pine, oak + hickory, and mesophytic species).

Methods

We obtained FHM plot data for the Southeastern area through 1991-2005. The 259 plots selected for this study were located in Alabama, Georgia, and Virginia since plots were not established in other states in the Southeastern United States prior to 1998. Sapling data were obtained at the subplot level from a total of 608 subplots. Within each subplot, all saplings with diameter at breast height (DBH) equal and greater than 2.54 cm (1 inch) but equal and less than 12.45 cm (5 inches) were measured.

Annual relative growth rate (cm^2 cm^{-1} yr^{-1}) was calculated for each sapling re-measurement by dividing the basal area increment by the initial DBH and the number of growing seasons between measurement intervals. The time interval between measurements varied because the FHM program measurement protocols were revised during the study period. Annual mortality rates within a subplot were calculated for each species and were expressed as percent removed per year (% yr^{-1}). The total basal area removed between measurements was calculated for each species. Saplings defined as dead and those not re-measured were considered removed due to mortality. Annual recruitment rates within a subplot were also calculated for each species and were expressed as stem per hectare recruited per year (# ha^{-1} yr^{-1}). The total sapling numbers recruited between measurements was counted for each species. Saplings defined as ingrowth on microplot (tree history = 2) were considered recruited.

Monthly PDSI values during the study period for each of the counties in which FHM plots were located were obtained from the National Oceanic and Atmospheric Administration (NOAA). Annual and growing-season averages (May-Sept) were calculated for each year. Preliminary analyses indicated that the minimum growing season PDSI (i.e., the most severe growing season drought) between measurement intervals was a better drought indicator and was more correlated with relative growth and mortality rates than the mean annual or growing-season PDSI (Klos et al. 2009). Drought conditions were assigned to each interval of plot measurements based on the minimum growing-season PDSI using a classification similar to that used by NOAA: 1) no drought, 2) mild drought, and 3) moderate and severe drought (Table 1).

Table 1. Drought severity classification based on the minimum growing-season PDSI

Drought Class	Severity	PDSI
1	No Drought	> -1.9
2	Mild Drought	-2.9 to -1.9
3	Moderate to Severe Drought	< -2.9

Due to limitations within the data, three species groups were identified for subsequent analyses: 1) pine (Pinus), 2) oak (Quercus) + hickory (Carya), and 3) mesophytic species. The mesophytic species group includes maple (Acer), birch (Betula), beech (Fagus), ash (Fraxinus), sweetgum (Liquidambar), yellow poplar (Lirodendron), magnolia (Magnolia), tupelo (Nyssa), and sassafras (Sassafras). These three species groups were identified to represent an array of site moisture gradients with pines typically occurring on dry ridges and mesophytic species typically occurring on moist lower lying areas.

The mixed model procedure PROC MIXED in the SAS 9.1 statistical software (SAS institute, 2004) was used to examine the effect of drought severity on sapling growth and the Fisher's least significant difference (LSD) test was used to determine differences among the drought classes for annual relative growth rate. For annual mortality and recruitment rates, because over 70% of sampled subplots for each species groups were recorded as zero, we used two-way Chi-square analysis to determine if annual mortality and recruitment rates are dependent on drought class by separating annual mortality and recruitment rates into two classes: zero or no-zero. The analysis was conducted in the SAS 9.1 statistical software (SAS institute, 2004) using procedure PROC FREQ.

Acknowledgements

Results

All three species groups showed a general decrease in mean annual growth rate with increasing drought severity (Figure 1). For the oak + hickory species group, significant differences were found between the no-drought class (1) and the two drought severities (2-3) ($P = 0.0109$ and 0.0062, respectively). For the mesophytic species group, significant differences were also found between the no-drought class (1) and the two drought severities (2-3) ($P = 0.0178$ and 0.0009, respectively). Although the greatest decreases were found along the drought severity, no significant differences were observed among drought classes within the pine species group when the effects of stand conditions were adjusted..
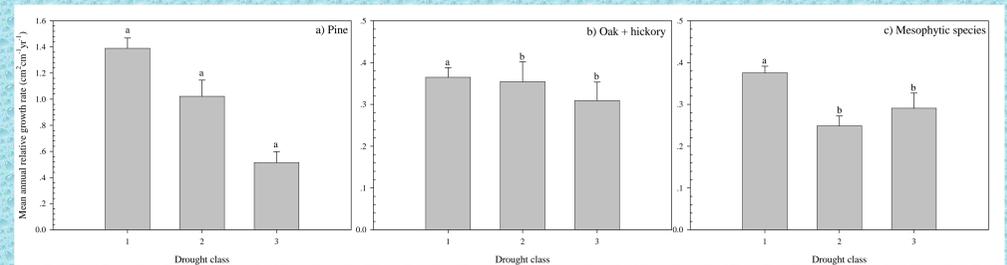

Figure 1. Annual relative growth rates (Mean + 1 SE) by drought class for the pine (a), oak + hickory (b), and mesophytic species (c) groups.

The Chi-square analysis showed that annual sapling mortality rate was significantly dependent on drought class for all three species groups ($P = 0.0012$, < 0.0001, and < 0.0001 for pine, oak + hickory, and mesophytic species, respectively). For each species group, the proportion of sampled subplots in which sapling mortality was detected consistently increased with increasing drought classes, indicating sapling mortality increased with drought severity (Figure 2).
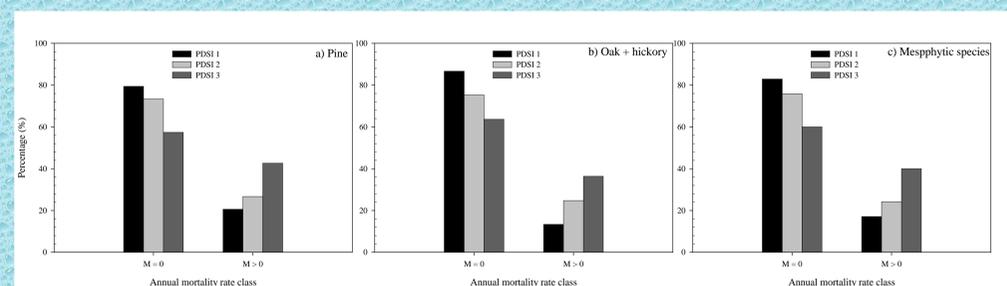

Figure 2. The separated percentage (%) of annual mortality rate (% yr^{-1}) for the pine (a), oak + hickory (b), and mesophytic species (c) groups by drought class. M = 0 refers to those plots recorded no sapling mortality during remeasurements; M > 0 refers to those plots recorded sapling mortality during remeasurements.

However, the Chi-square analysis showed that annual recruitment rate was only significantly dependent on drought class for the oak + hickory species group ($P = 0.0164$), but not for the pine and mesophytic species groups($P = 0.1758$ and 0.2714, respectively). Within the oak + hickory species group, the proportion of subplots had sapling recruitment was higher for two drought classes (Figure 3).

Figure 3. The separated percentage (%) of annual recruitment rate (# ha^{-1} yr^{-1}) for the oak + hickory group by drought class. R = 0 refers to those plots recorded no sapling recruitment during remeasurements; R > 0 refers to those plots recorded sapling recruitment during remeasurements.
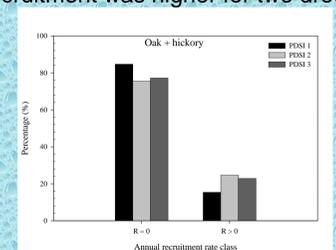
Conclusions

Our findings indicate that saplings of the oak + hickory and mesophytic species are sensitive to drought as they exhibited significant reductions in growth and increased probability of experiencing mortality with increasing drought severity. However, oak + hickory also had better recruitment on plots experience drought, suggesting oak saplings are more drought tolerant than mesophytic species. The saplings of the pine species exhibited no significant reduction in growth rate, but higher mortality rates were also observed during drought episodes. These results indicate that, if drought episodes become more frequent and severe, future forests in the southeastern US may develop into sparser stands of lower productivity due to increased mortality, reduced growth, and poorer recruitment, with increasing dominance of oak + hickory and pines at the expense of mesophytic species in the canopy.

Literature cited

Palmer WC (1965) Meteorological Drought. Research Paper Number 45. Department of Commerce, Washington, DC.
Klos RJ, Wang GG, Bauerle W, Rieck JR (2009) Drought impact on forest growth and mortality in the southeast USA: an analysis using Forest Health and Monitoring data. Ecological Applications,19, 699-708.
SAS Institute (2004) SAS/STAT User's Guide. SAS Institute Inc., Cary, NC, USA.