

# Modeling the impact of drought severity on red maple growth in Southeastern forests



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## Introduction

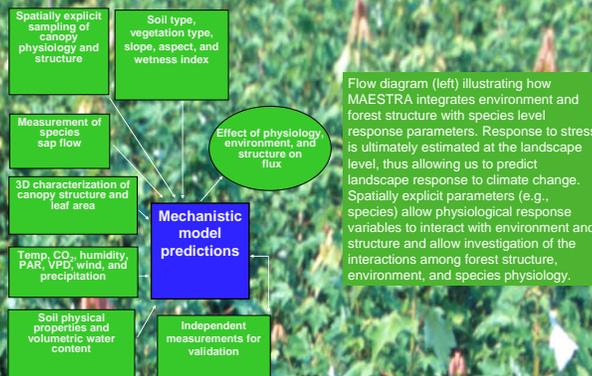
Global climate change, especially global warming due to increased greenhouse gas concentrations, has recently increased concern regarding forest potential evapotranspiration. Several climate change scenarios suggest that elevated forest water use will lead to frequent and/or intense drought episodes within the Southeastern USA. Therefore, the ability to forecast and predict the response of forest ecosystems to various drought conditions is important for forest ecosystem management and sustainability. Response of forest ecosystems to climate change depends on many complex biological interactions and in many instances, the use of models is the only practical means to quantify the outcomes of environmental and biological interactions. During the years 1998-2001, extensive forest areas within the Southeastern USA experienced severe drought conditions (defined by the Palmer Drought Severity Index (PDSI)) (Palmer 1965). In this study, MAESTRA, a three-dimensional biological process model (Medlyn et al. 1999), was applied within the region to assess the impact of drought severity on forest carbon balance.

## Objectives

Our objective was to investigate forest productivity from 1991-2005 under various drought conditions. Specifically, we 1) calibrated MAESTRA to account for drought severity using red maple growth data from the Forest Health and Monitoring (FHM) program and 2) examined net carbon accumulation in relation to drought severity/soil moisture availability.

## Methods

We obtained FHM plot data for the Southeastern area through 1991-2005. Annual relative growth rate ( $\text{in}^2 \text{in}^{-1} \text{yr}^{-1}$ ) was calculated for each red maple tree re-measurement from plots located in Alabama, Georgia, and Virginia. Monthly PDSI values from 1991-2005 were obtained for each of the plots from NOAA. Growing season averages (May-Sept) were calculated for each year. Preliminary analyses indicated that the minimum growing season PDSI (i.e., most severe drought) between measurement intervals was a better drought indicator and was more correlated with relative growth rates than the mean PDSI. Drought conditions were assigned to each interval of plot measurements based on the minimum PDSI using a classification similar to that used by NOAA: 1) no drought, 2) mild drought, 3) moderate drought, and 4) severe drought (Table 1). The mixed model procedure PROC MIXED in the SAS/STAT software (SAS Institute Inc. 1990) was used to examine the relationship between red maple relative growth rate and drought severity and stand condition variables. Stand condition variables were included in the analyses to account for varying stand conditions and included total basal area ( $\text{ft}^2 \text{ac}^{-1}$ ), total tree density (# trees  $\text{ac}^{-1}$ ), tree species richness (# spp subplot<sup>-1</sup>), slope (%), and stand age (years). The mean growth rate by drought class was calculated and the LSD test was used to determine differences among the drought classes using a p-value of 0.1 (Figure 1). We created a simulation environment where *Acer rubrum* L. (red maple) trees were grown at 12 X 12 m spacing. Three tree sizes were randomly located in a simulated 100 tree plot to represent a multi-cohort forest. The small, medium, and large tree sizes were assigned height and dbh values of 6, 12, and 18 m and 12.5, 25, and 50 cm, respectively. Hourly climate data from 1998-2005 were obtained from AWIS. Drought severity was incorporated into the model through calibration of the soil moisture deficit parameter ( $\delta M$ ) (Bauerle et al. 2002). Soil moisture deficit is a measure of the actual root zone volumetric soil moisture content in relation to the maximum, actual, and minimum soil moisture holding capacity. Soil moisture deficit values range from 0 to 1 with larger values representing a higher soil moisture deficit. Based on the LSD tests of the FHM data, soil moisture deficit values were assigned to drought conditions to represent similar differences of net photosynthesis ( $A_{\text{net}}$ ) and were classified as follows: 1) minimal drought ( $\delta M=0.2$ ), 2) mild drought ( $\delta M=0.4$ ), 3) moderate drought ( $\delta M=0.6$ ), and 4) severe drought ( $\delta M=0.8$ ). Simulations were conducted for each of the drought severities through 1998-2005. Annual growing season  $A_{\text{net}}$  ( $\text{kg C m}^{-2} \text{yr}^{-1}$ ) were quantified for three randomly selected large trees via MAESTRA simulations.



Flow diagram (left) illustrating how MAESTRA integrates environment and forest structure with species level response parameters. Response to stress is ultimately estimated at the landscape level, thus allowing us to predict landscape response to climate change. Spatially explicit parameters (e.g., species) allow physiological response variables to interact with environment and structure and allow investigation of the interactions among forest structure, environment, and species physiology.

## Results

The  $A_{\text{net}}$  for the four drought classes during the years 1998-2005 are illustrated in Figure 2. The mean net carbon gain for the minimal, mild, moderate, and severe drought conditions were 0.36, 0.35, 0.31, and 0.15  $\text{kg C m}^{-2} \text{yr}^{-1}$ , respectively. As hypothesized,  $A_{\text{net}}$  declined as soil moisture deficit increased. No significant difference in annual productivity was observed between the minimal, mild, and moderate drought severity conditions. The effect of soil moisture stress was more pronounced within the severe drought condition as  $A_{\text{net}}$  of the severe drought class was significantly lower than that of the other three drought classes. The severe drought condition yielded annual productivity estimates approximately a third of those observed in the minimal drought condition.

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 - -1.9
3	Moderate Drought	-3.9 - -2.9
4	Severe Drought	< -3.9

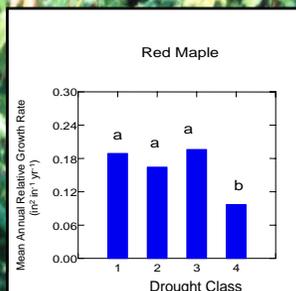


Figure 1. Mean annual relative growth rates by drought class for red maple.

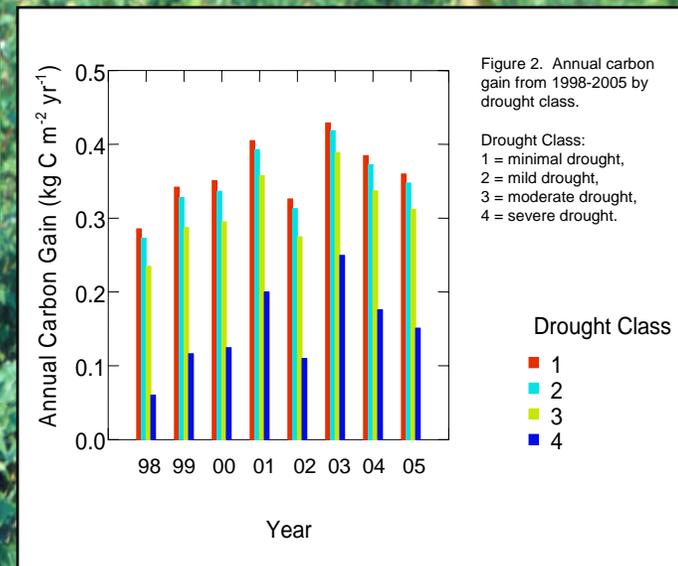


Figure 2. Annual carbon gain from 1998-2005 by drought class.

Drought Class:  
1 = minimal drought,  
2 = mild drought,  
3 = moderate drought,  
4 = severe drought.

Drought Class

1  
2  
3  
4

## Discussion & Conclusions

This study demonstrates the negative impact of water stress on net tree carbon accumulation. Net tree growth declines as available soil moisture becomes more limiting. The decline is more substantial as higher levels of moisture stress are reached. If drought episodes continue to intensify and/or become more frequent, a decline in net tree growth can prove detrimental for Southeastern forests. Therefore, the ability to predict drought response under various climate change scenarios is a necessity. This study shows that MAESTRA has the potential to model forest response to water stress under various levels of drought severity. Although this study was conducted using red maple as a model species, MAESTRA can be calibrated for other tree species to examine drought induced moisture stress. We have validated the water stress response of tree growth under various levels of drought using Forest Health and Monitoring (FHM) data and are now poised to assess the Southeastern USA regional forest response.

## Literature cited

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