Relating Riparian Health to River Hydrodynamics and Climate Using Dendrochronology and Tree Ring Carbon Isotope Composition

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Introduction

Bottomland hardwood forests and associated habitats occur in significant amounts along the floodplains of the rivers and bayous in coastal counties of the Upper Texas Gulf Coast. Meandering through coastal Texas, the lower Brazos, San Bernard and Colorado rivers combine to form the Columbia bottomland hardwood forests and help support the region's hydrology and biodiversity. Large portions of floodplain forest in this region have been removed and land cover is now a mix of forest, cropland, and pasture. Additionally, this region has been experiencing a steep increase in the frequency and severity of floods and droughts over the past five decades. Although natural disturbances are a regular part of ecosystem function, extreme events are becoming more and more common. As a result of the fluctuations in water availability due to this hydro-climate change, these forests are subjected to a variety of hydrological stresses.

The frequency and intensity of climate extremes related to precipitation and temperature have shifted significantly due to climate change and variability. These changes have resulted in severe floods and droughts. Extreme hydroclimatic events can have exacerbating effects on forest health and fundamentally change a wide range of ecosystem processes and services. Under the current climate change scenario, the Columbia bottomland hardwood forests, which are one of the most diverse ecosystems in the state, are hydrologically critical for the region. With regard to precipitation changes, climate models project more precipitation in some regions as a result of an increase in the total amount of water in the atmosphere under a warming climate, while mid-latitude regions, are projected to have less precipitation. Projected impacts of climate change in Texas have previously been assessed based on global climate model simulations and downscaled regional climate information.

Quercus species adjacent to flood-prone rivers adapt to prolonged inundation by reducing the mean transverse area of the earlywood vessels in their annual rings. Vessel reductions are confined to the year of inundation; tree anatomy returned to normal in subsequent non-flood years. Prolonged inundation of trees during spring and early summer induces the development of anatomical anomalies (flood rings) that provide a proxy record of extreme floods. The timing of flooding relative to cambial activity is critical, because flooding that occurs during the tree's dormant period will not disrupt hormonal flow and anatomical development. While, ring-widths are more suitable for studying drought signals, ring anatomy is a better indicator of floods.

A number of studies have suggested that better climate reconstructions may originate with the inclusion of additional tree-ring attributes aside from ring width, e.g., latewood density and tree-ring stable carbon isotopes ($\delta^{13}C$). Tree-ring $\delta^{13}C$ is an indirect record of the available internal leaf CO_2, which is controlled by a balance between stomatal conductance and photosynthetic rate in response to the environment. Thus, dendroisotopic work combines the advantage of the precisely dated annual resolution of tree rings with the sensitivity of stable isotope ratios as governed by ecophysiological processes in response to the environment.

Objectives

- Understand the impact of hydro-climate change on bottomland hardwood forests and quantify the temporal variation in growth inhibition and physiological stress.
- Characterize study sites according to their response to varying hydro-climatic conditions and identify possible factors causing contrasting responses.

Hypotheses

- Higher growth inhibition and physiological stress will be observed during drought years across all sites.
- Ring-widths will be closely related to growth patterns at a regional scale and indicate cumulative growth response of vegetation to climatic conditions.
- $\delta^{13}C$ will identify physiological stress at a finer (site or plot-level) scale.
- Overall, drought-stress will be more evident than flood-stress because bottomland forests are expected to be adapted to flooding.

Materials and Methods

Study Area Profile:

The study was conducted at four different sites located within the San Bernard Wildlife Refuge, Brazoria County, Texas. The sites are located at an elevation of about 16 m above MSL. The average annual maximum temperature is approximately 26° C and the annual minimum temperature is approximately 15° C. The area receives a mean annual rainfall of 1143 mm, with an average relative humidity of ~70%. The sites are located in the Linnville Bayou watershed of the San Bernard River Basin. As these forests are situated in the floodplain, sloughs are a common occurrence, which inundate significant parts of the forest. The soils are mainly vertisols and alfisols dominated by clay, loam and sandy loam texture. The soils series include Aris fine sandy loam, Bacliff clay, Edna loam, Leton loam, Pledger Clay and Churnabog clay.

Two 30 m circular study plots at a distance of 300-400 m with three Water Oak (*Quercus nigra*) trees were established at each site.

Tree Core Sampling:

Three <400 mm long tree core samples were extracted at breast height from each tree. Healthy trees with no injuries like cavities and scars or diseases were selected. Two cores were processed and used for ring-width measurements while the third core was used for $\delta^{13}C$ analysis. The cores were stored and transported in paper straws for protection and faster drying.

Dendrochronology:

The cores were dried at 60^{o} C and mounted on 9.5 x 9.5 mm grooved core mounts. The mounted cores were sanded using progressively finer grades of sandpaper (60 to 400 grit). Tree-ring widths were measured using MeasureJ2X program. COFECHA was used to statistically assess the quality of cross-dating and measurement accuracy. A final standardized chronology was generated using ARSTAN program.

Climate Data:

Daily climate summaries from three weather stations (Bay City, New Gulf and Wharton) and Palmer's Drought Sensitivity Index (PDSI) records for the Upper Texas Gulf Coast ecoregion were collected from the NOAA NCEI database for the period of 1950-2016.

Dendroclimatology:

Tree growth-climate analysis was carried out by creating correlation matrices and linear regression models of ARSTAN chronologies versus monthly precipitation, PDSI and maximum temperature to determine the growth response of trees at each site to hydro-climatic variation. Significantly correlated months were aggregated to determine the growing season.

Tree-ring $\delta^{13}C$ analysis:

4-year tree-ring composites from anomalously dry (narrow rings) and wet (wide rings) years were selected. For $\delta^{13}C$ analysis, α-cellulose was extracted from tree-rings in a Soxhlet extraction assembly by applying a slightly modified version of the Jayme-Wise Method. $\delta^{13}C$ in tree-ring α-cellulose was analyzed using an elemental analyzer interfaced with an isotope ratio mass spectrometer operating in continuous flow mode.

$\delta^{13}C$ in tree-ring α-cellulose was analyzed using an elemental analyzer interfaced with an isotope ratio mass spectrometer operating in continuous flow mode in the Stable Isotopes for Biosphere Science (SIBS) Lab, Texas A&M University. Carbon isotope ratios were presented in δ notation:

$\delta = [(R_{SAMPLE} - R_{STD})/R_{STD}] \times 10^3$

where R_{SAMPLE} is the $^{13}C/^{12}C$ ratio of the sample and R_{STD} is the $^{13}C/^{12}C$ ratio of the V-PDB (Vienna Pee Dee Belemnite) standard (Coplen 1996).

Results

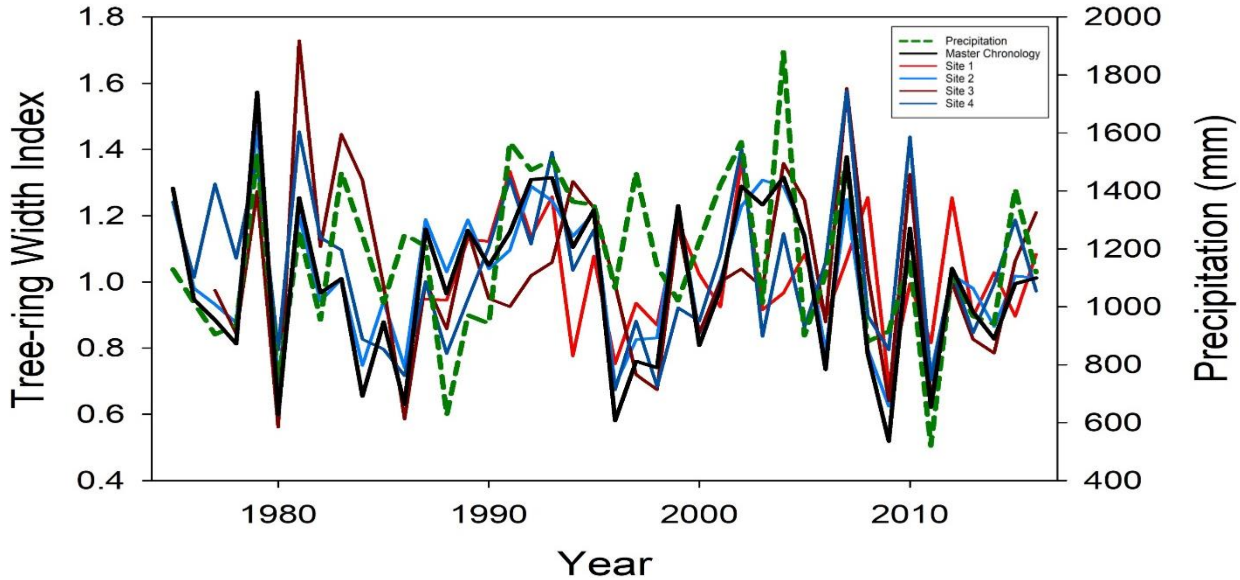

Figure 1: Precipitation (dotted green) with tree-ring width master chronology (black) and individual site chronologies from 1975-2016.

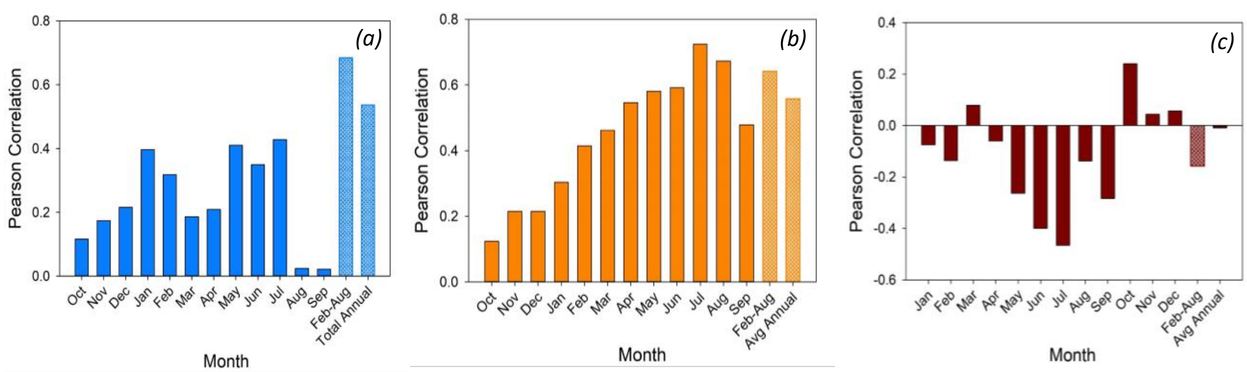

Figure 2: Correlation coefficients of master ring-width series and monthly precipitation (a), monthly PDSI (b) and average monthly maximum temperature (c).

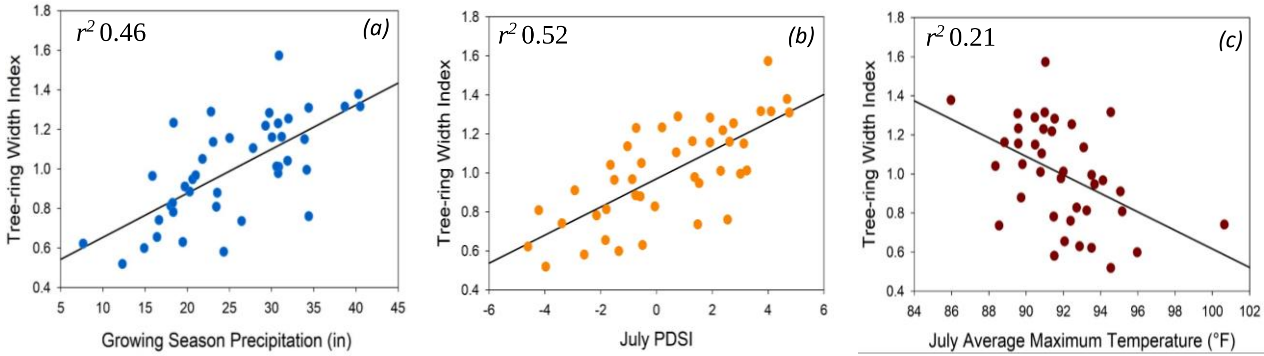

Figure 3: Linear regression models of master ring-width series and total growing-season precipitation (a), PDSI for July (b) and average maximum temperature for July (c).

The individual site-level tree-ring width chronologies showed no significant difference ($p = 0.981$) and the master chronology had a series intercorrelation of 0.317. A positive increase in radial growth was observed with increase in precipitation and PDSI, while the growth decreased with increasing average monthly maximum temperature. Radial growth increment was found to be closely associated with the growing season (February-August) precipitation (0.684) as compared to individual months. However, for PDSI (0.724) and average monthly maximum temperature (-0.465), radial growth had the highest correlation with July records. Precipitation and PDSI were found to be stronger drivers than maximum temperature. No significant relationship was observed between growth and climatic variables from the previous growing season.

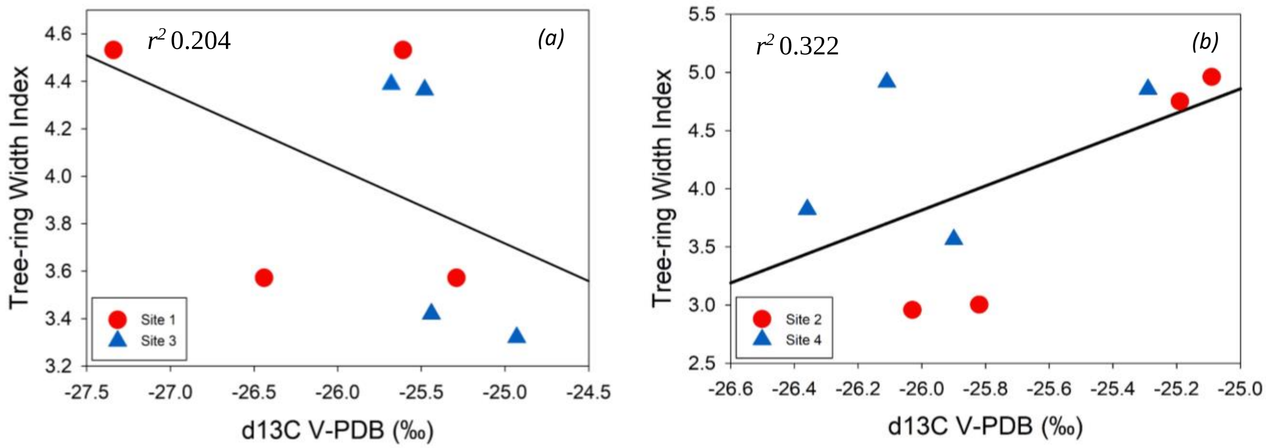

Figure 4: A comparison between the width index and $\delta^{13}C$ shows a negative relationship for sites 1 and 3 (a) and a positive relationship for sites 2 and 4 (b)

Large inter-site variation in $\delta^{13}C$ was observed between sites (2.79-4.24‰ for wet years and 0.53-1.50‰ for drought years). As expected, $\delta^{13}C$ values decreased with radial growth increment (r^2 0.204) at two of our sites (1 and 3), while at the other two sites (2 and 4), an increase in $\delta^{13}C$ values was observed (r^2 0.322).

Conclusion

Tree-ring widths indicated cumulative growth response of vegetation to regional climatic conditions. They were more consistent over a larger spatial and temporal scale. $\delta^{13}C$ measurements were more responsive and sensitive to wetness conditions at individual sites. Although growth is directly related to climatic variation in this region, physiological stress and water use efficiency of trees is highly dependent on site-specific conditions. Growth inhibition was consistently observed during dry years in all the sites, while drought-induced moisture deficit stress was evident only in trees at sites 1 and 3. Contrary to our hypothesis, trees at sites 2 and 4 showed more physiological stress during excessively wet years possibly emanating from flooding-induced stress caused by waterlogging. Trees at these two sites did not show a notable stressful response to droughts. Site-specific edaphic and topographic conditions play a significant role in driving response of vegetation to hydro-climate change in this landscape.

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