TREE-RING RESEARCH, *Vol. 76(2), 2020, pp. 89–93*
DOI: http://dx.doi.org/10.3959/TRR2019-9

RESEARCH REPORT

MICROELEVATIONAL DIFFERENCES AFFECT LONGLEAF PINE (*PINUS PALUSTRIS* MILL.) SENSITIVITY TO TROPICAL CYCLONE PRECIPITATION: A CASE STUDY USING LIDAR

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ABSTRACT

Latewood ring widths of longleaf pine (*Pinus palustris* Mill.) growing on Carolina bay sand rims on the coastal plains of North Carolina are effective recorders of tropical cycone precipitation (TCP). Longleaf pine are hypothesized to be effective recorders of TCP because of their extensive lateral root structure that is exposed to enhanced soil moisture when TCP events raise the water table to root level, but this hypothesis has not been empirically tested. In this study, we used a combination of North Carolina Phase 1 LiDAR and high-precision georeferenced data to investigate the relationship between radial tree growth, TCP, and microelevation. Our findings suggest that the strength of correlations between latewood ring widths and TCP are positively correlated ($p < 0.05$) with tree elevation on Carolina bay sand rims, resulting in greater sensistivity of trees at higher elevations. These findings suggest that in some environments, microelevational differences (<1 m) may significantly affect climate/radial growth relationships and the use of high-resolution LiDAR technology may be an effective tool for better understanding the role of microtopography on radial growth patterns.

Keywords: Carolina bays, microelevation, LiDAR, tropical cyclone precipitation, longleaf pine.

INTRODUCTION

Latewood ring widths of longleaf pine (*Pinus palustris* Mill.) are strongly associated with tropical cyclone precipitation (TCP), and thus serve as an effective proxy to document variations in TCP (Knapp *et al.* 2016). Knapp *et al.* (2016) targeted sampling from canopy-dominant trees within remnant stands of old-growth (*i.e.* >150 years) longleaf pine on Carolina bay sand rims along the coastal plains of North Carolina. The sandy rims rise *ca.* 1–1.5 m above the surrounding pocosin plains and are characterized by a gently sloping (<1–2°) convex profile. Longleaf pine growing on the rims are classified as savanna woodlands with an understory of wiregrass (*Aristida stricta* Michx.) (Frost 2007). These old-growth woodlands remained intact as they were either too small and/or inaccessible to economically harvest (personal observation).

The root structure of mature longleaf pine is characterized by a central taproot reaching depths of >4 m, lateral (secondary) taproots between 1.5 and 4 m in depth, and shallower (0.3–1 m) lateral roots that extend >20 m from the tree base (Figure 1, Heyward 1933). Knapp *et al.* (2016) posited that the positive relationship between latewood width and TCP ($r = 0.71$) was caused by a post-storm rise in water-table depth that inundated the shallow lateral roots of the tree causing a growth flush (Figure 1).

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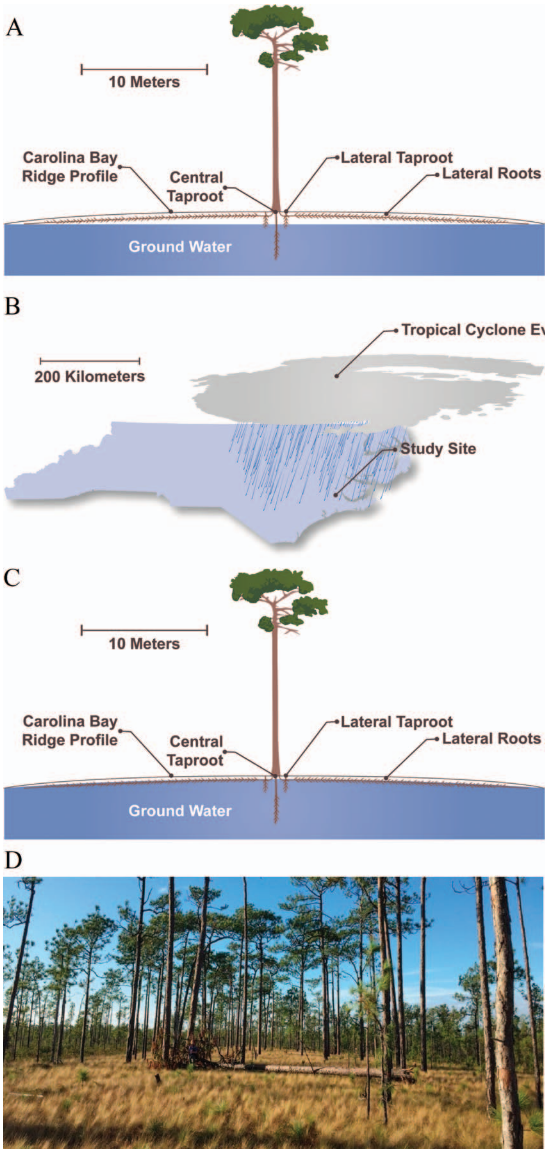

Figure 1. Hypothesized relationship between latewood growth and TCP. (A) cross-section of a longleaf pine on Carolina bay sand rim with root structure (Heyward 1933) shown; (B) tropical cyclone precipitation over North Carolina coastal plain; (C) rise in water table post-storm to the height of lateral roots, which we posit triggers a latewood growth flush; and, (D) panoramic view of the Catfish Lake Carolina bay sand rim showing the convex profile.

A major constraint in processing and analyzing microelevational data is the tools employed during the data collection process. Lower-end GPS devices commonly used in tree-ring science (*e.g.* Garmin eTrex series) can produce location readings that differ by up to 3.65 m from the true point of intrest (Garmin 2019). Moreover, Drosos and Malesios (2012) found that a low-end Garmin GPS reciever, in a closed canopy forest, produced positional errors up to 5.08 m, 3.50 m, and 7.55 m in the x, y, and z plane, respectfully. The magnitude of such errors inhibits accurate microelevational analysis, especially on Carolina bay sand rims where local relief is commonly less than 1.5 m.

Literature surrounding tree ring and climate interactions at the microelevational level is limited. Mircoelevation, collected with a carpenters's laser level, influenced the vegetation structure of peatland environments in New York, USA (Langdon 2014). Microtopograpahic geomorphic changes, calculated with Light Detection and Ranging (LiDAR), had a relationship with vegetation structure modification on barrier islands in the Gulf of Mexico (Anderson *et al*. 2016). Relatively higher elevation sites (ranging from 0 to 3 m, calculated from LiDAR) acted as a refuge from salt water from storm surges in the Florida Keys, resulting in older forest stands with differing stand complexity compared to lower elevations (Harley *et al*. 2015). Microelevation (calculated using a topograph) along with plant structure, soil pH, and soil temperature, determined germination and survival rates of native and invasive arbor vitae species in Cedar Bog Nature Preserve, Ohio, USA (Collins *et al*. 1981). Although all of these studies are tangentially related to tree-ring science at the mircoelevational scale, we find that a high-resolution (*i.e.* LiDAR) dendroclimatological assessment of microelevational influences on tree growth is lacking.

In this study, we test the viability of the Knapp *et al*. (2016) hypothesis by examining the relationships between latewood growth, TCP, and rim elevation using high-precision LiDAR and GPS measurements. Specifically, this study aims to test if trees growing along the apex of the sand rim are more sensitive to TCP as their lateral roots would be exposed to elevated soil moisture only when a sufficiently large tropical storm raised water tables 0.3–1 m. Furthermore, it is our goal that this nuanced approach to understanding miroelevational influences on tree growth can become applicable in tree-ring science as LiDAR becomes increasingly accessable to the research community and the general public.

METHODS

We sampled 31 longleaf pine trees on a 2.7 ha Carolina bay (Catfish Lake; hereafter CFR) sand rim in the Croatan National Forest (34.972, −77.119) using a hand-held 5.03 mm diameter increment borer. The rims are classified as the Leon Sand mapping unit (NRCS 2015), which comprises sand down to 2 m in depth and the water table depth down to 0.3 m. We obtained two sample cores per tree from opposite sides at *ca*. 1.3 m height on the stem. We glued the collected and dried samples to wooden mounts, sanded to 400 μm grit, and crossdated using the list method (Yamaguchi *et al*. 1991). We measured earlywood, latewood, and total ring width of each sample using WinDendro (Regent Instruments, Inc. 2011) to 0.001 mm accuracy. We verified our crossdating using the program COFECHA (Holmes 1983) and individually standardized the core samples using ARSTAN (Cook 1985). Following the methodologies of Knapp *et al*. (2016), we standardized the samples using negative exponential detrending as longleaf pine growing on Carolina bays have an open canopy and used the standardized (STD) version of the cores for analysis.

We recorded the geographic position of each sampled tree on CFR using a Trimble GeoExplorer 6000 GeoXH handheld GPS unit, which provides decimeter accuracy in real time (Trimble 2011). We plotted the latitudinal and longitudinal position of each tree in ArcMap version 10.5.1 using a North Carolina State Plane coordinate system (ESRI 2017). In order to assess the elevation of sampled trees, we used LiDAR data from North Carolina's Floodplain Mapping Program (NC Flood Mapping Program, 2014). Data for our region were collected in 2014 during phase one of mapping and are available in Digital Elevation Model (DEM) format. We transposed the locations of the sampled trees onto the DEM in ArcMap and used the "Extract Values to Points" tool in the spatial analyst extension to acquire unique elevation values for each tree we sampled.

We obtained TCP data from Knapp *et al*. (2016) for 1953–2014 and extended the tree-ring record using their methodology during 2015–2018. TCP data represent rainfall totals from TCs passing within a 223 km radius rain field from New Bern, North Carolina (GHCND:USW00093719, 13 km NE of site) during June 1st–October 15th, which is the period associated with latewood growth (Knapp *et al*. 2016). We correlated (using Pearson's r) the STD growth of individual sample cores with TCP from New Bern during 1953–2018. For each tree with two samples, we selected the sample with the highest correlation. Prior to employing an independent-samples t-test to determine significance between means, we converted the r-values to z-values using Fisher's r to z transformation (Fisher 1921). We then split the latewood/TCP generated z-values into two equal-sized groups ($n = 12$) based on the elevation of the tree relative to the base of the bay sand rim (hereafter, relative elevation): a high group and a low group with mean elevation separated by *ca*. 0.5 m. Lastly, we correlated (using Pearson's r) STD tree growth and TCP with relative elevation.

RESULTS

We were able to successfully crossdate and measure 41 cores from the 31 trees on CFL. Excluding trees with two cores, the final sample size was 24 (*i.e.* 24 cores from 24 trees correlated with exact relative elevations of those trees). The relationship between climate/growth responses with relative elevation was significant ($p < 0.01$) and positive ($r = 0.535$), indicating that greater climate sensitivity exists at higher elevations on CFR (Figure 2). There were only three trees that did not have significant values among the 24 samples, and these represented two of the three lowest elevations (Figure 2). Additionally, the mean z-value (0.50) of trees growing in the higher-elevation group was significantly ($p < 0.05$) greater than those trees in the lower-elevation group (0.35). Likewise, mean relative elevation difference between the higher and lower groups (0.92 m *vs.* 0.39 m) was significantly different ($p < 0.01$).

DISCUSSION AND CONCLUSIONS

These results support our hypothesis that trees growing on the periphery of Carolina bays are less sensitive to TCP. We postulate that this lack of TCP

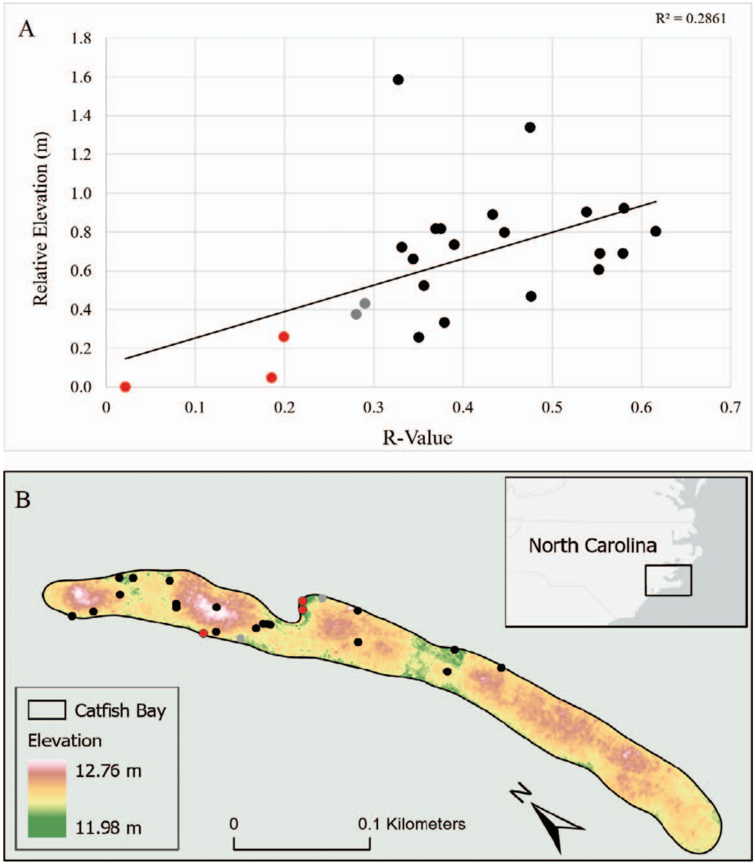

Figure 2. The (A) scatterplot showing the relationship between Pearson's r values (*i.e.*, individual tree correlations between latewood width and TCP) and relative elevation of trees growth on a Carolina bay in coastal North Carolina and (B) the position of individual trees on Catfish Lake bay. Red dots on both graphics indicate non-significant r values, gray dots indicate correlations significant at 95% confidence interval, and black dots indicate correlations significant at 99% confidence interval.

sensitivity in lower elevation trees is a function of continuous access to moisture in the soil because of proximity to the water table. Samples collected at higher elevations had progressively greater TCP sensitivity, supporting our theory that longleaf pine growing at higher mircoelevations are more sensitive to changes in the water table caused by precipitation from TC events.

At CFR, the strong relationship between latewood sensitivity and elevation provides (1) insights on why longleaf pine have a strong response signature with TCP amount, and (2) evidence that relative elevation differences of *ca.* 0.5 m may signficantly influence latewood responses to TCP. We provide evidence that latewood formation, which coincides with the tropcial cyclone season in the Atlantic Basin, has a stronger relationship to TCP as elevation increases on Carolina bays.

The use of LiDAR to evaluate climate/growth responses of trees at the microelevational level has not been widely used in tree-ring science, suggesting employment of this technique may be beneficial in low-relief environments, particularly where minor elevational differences (*i.e.* < 0.5 m) may correspond with significantly different radial growth rates. Our goal with this project was to shed light on the nuances and complexities of trying to evaluate tree growth along spatial and elevation spectrums. Samples in tree-ring science are often collected at wide spatial scales without considering microelevational influences. We use this study as a tool to advise tree-ring researchers to consider variables of tree growth at a wide variety of spatial scales.

ACKNOWLEDGMENTS

This project was funded by NSF grant GSS-1660432. We thank Andi Sigsbey for the development of Figure 1. We also thank April Kaiser, Tyler Mitchell, Jeffy Summers, and Andrew Walker for field and/or laboratory assistance.

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Received 30 August 2019; accepted 13 April 2020.