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Dendroclimatic Reconstruction From Bald Cypress in Southwestern Indiana

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DENDROCLIMATIC RECONSTRUCTION FROM BALD CYPRESS IN SOUTHWESTERN INDIANA

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by

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ABSTRACT

In the United States, bald cypress (*Taxodium distichum*) is generally recognized as an important component of the forested wetlands found in the Southwestern Coastal Plain and the Mississippi River Valley (which extends to the southern Midwest). The lifespan of this deciduous species is important not only commercially, but also in an ecological capacity. This study focuses mainly upon the role the tree plays in its environment and how it can be used as an indicator of climate through drought/flood signals in the rings. Bald cypress is a long-lived tree that can be over 1000 years old and is sensitive to climate and ground water hydrology. Because of these factors it is a favorable choice for dendrochronological study in the region. According to the International Tree-Ring Database, a chronology of the species is not well defined for southwestern Indiana. This research provides this missing information and creates the northern most bald cypress chronology in the Midwest. The study site is located in the extreme southwest of Indiana around Hovey Lake (a backwater lake of the Ohio River) about 10 miles south of Mount Vernon, Indiana. Samples were taken from trees near the shore, both on land and in the water.This study dated some trees to 1855. Analysis of the tree rings, climate data, and river discharge data revealed that bald cypress are not declining in southwestern Indiana. The rate of tree ring growth increases as PDSI does and the rate of river discharge does not seem to affect growth much at all. Even though this is the northernmost bald cypress chronology in the midwest and therefore should be stressed according to the theory of ecological amplitude, this chronology does not fall in the category with the highest series intercorrelation or mean sensitivity. The

construction of the dam in 1975 has overwhelmed the climate signal in these trees and the trees continue to be suppressed due to the current water level.

ACKNOWLEDGMENTS

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CHAPTER 1

INTRODUCTION

North American bald cypress (*Taxodium distichum*) is generally recognized as an important component of the forested wetlands found in the Southeastern Coastal Plain and the Mississippi River Valley (which extends to the southern Midwest) (Mitsch *et al.* 1979). Historically, the northern-most Midwestern U.S. boundaries for bald cypress have been defined as the Wabash Valley and eastward, south of 38 degrees and 25 minutes North latitude (Ridgway 1872). The United States government has declared the species "Threatened" (USDA, 2009), while on a more global scale, the International Union for Conservation of Nature (IUCN) has placed it into their Red List category of "Least Concern" (IUCN 2009).

This thesis focuses upon the role the tree plays in its environment and how it can be used as an indicator of climate through correlated temperature, precipitation, Palmer Drought Severity Index, or flood signals in the ring widths. Bald cypress is a long-lived tree and is sensitive to climate and ground water hydrology (Mitsch *et al.* 1979, Stahle *et al.* 1985, Earle 2008). Ancient, submerged bald cypress timbers have been found well preserved, that have allowed scientists to create chronologies over 1000 years long. The lifespan of this deciduous species is important in commercial, ecological, and academic capacities (Stahle *et al.*1985, Stahle *et al.* 1988, Wilhite and Toliver 1990). Because of these factors, this species is one of the best choices for use in dendrochronological studies of environment and climate in the region.

The Hovey Lake Site

This site is located in southwestern Indiana in Posey County, Section 14, T8S, R14 W on the east side of State Road 69. Hovey Lake is an approximately 1400 acre backwater lake of the Ohio River and is situated in the floodplains of both the Ohio and Wabash Rivers (Indiana DNR 2011). Much of this land is owned by the Indiana -DNR and is located near several Caborn-Welborn archaeological sites excavated by Indiana University and Southern Indiana University (Munson 2000; Figures 1 and 2).

Hovey Lake is roughly four miles east from the Wabash River, two miles from the Ohio River, and about two miles to the northeast of the John T. Myers Locks and Dam. Completed in 1975, this lock and dam station was formerly named Uniontown Locks and Dam until its renaming in 1996 (Locks and Dams Project Office, 2011). The main sampling took place on the central western shore of the lake, on Hovey Lake Fish and Wildlife land. Permission to core live trees and take sections from fallen trees was acquired and a permit was granted in 2009 by DNR officer Mark Pochon.

Hypotheses

1. Ring widths are expected to increase during flood events as measured by 67 years of Ohio River flood discharge data.

    a. Scientists have found that the width of bald cypress tree rings varies with the amount of flood water present (Welch 1931).

2. Bald cypress ring width will have a significant response to the Palmer Drought Severity Index (PDSI), a measure of dryness using temperaure and precipitation, on a scale of -6 (the most dry) to 6 (the most wet) (Palmer 1965).

   a. Along with lake levels, precipitation, and temperature, drought as measured with PDSI should also be factors that drive bald cypress tree growth at this site.

3. Bald cypress tree growth in Indiana is declining.

   a. The bald cypress sample would be showing a decrease in growth in the last few decades that is not related to river level or an age-related growth decline.

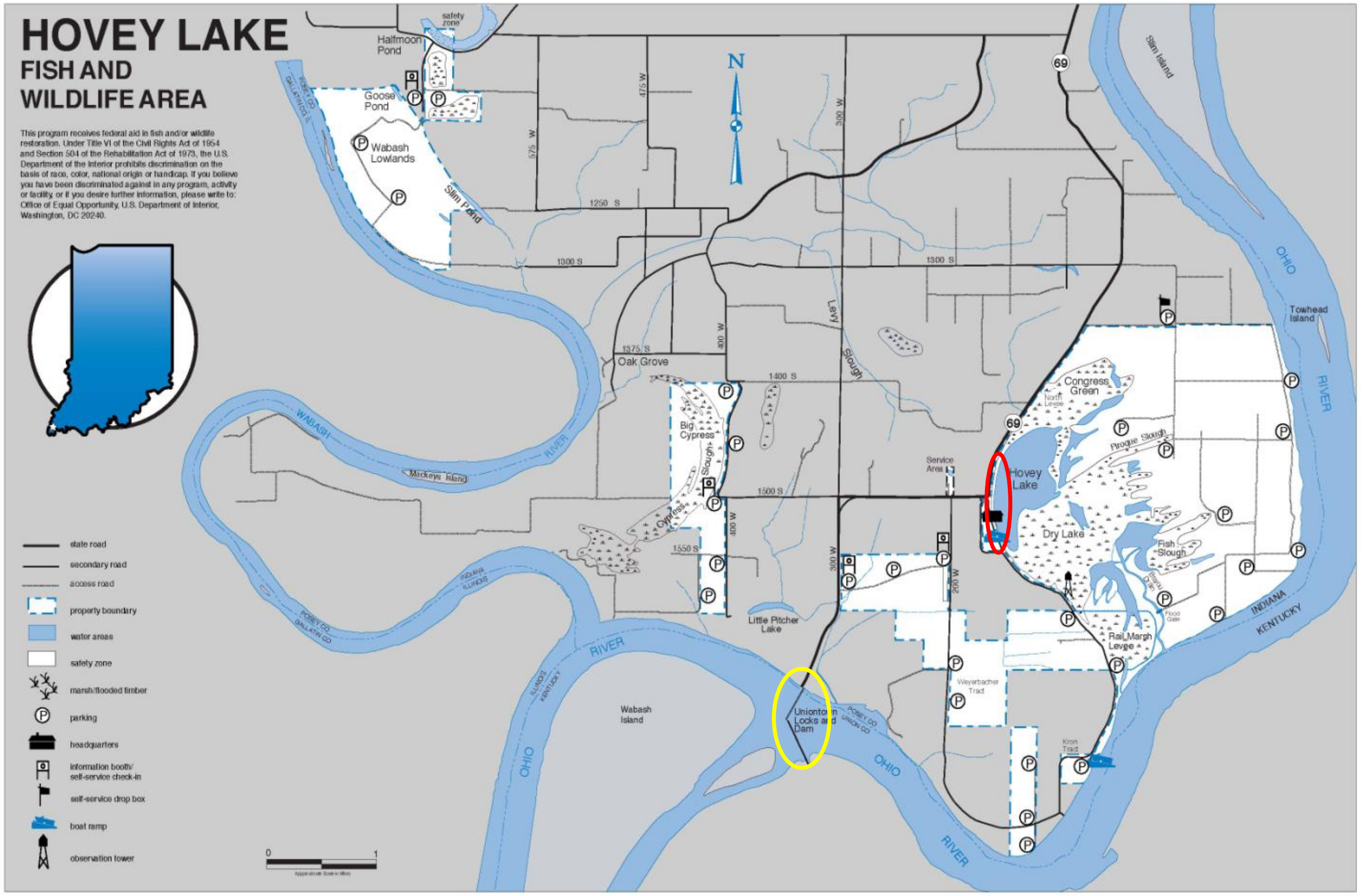

Figure 1. Map of the Hovey Lake Fish and Wildlife Area in southwestern Posey County, Indiana. The sample area is indicated by red oval and John T. Myers Locks and Dam (here labeled as Uniontown Locks and Dam) is circled in yellow. (Indiana DNR 2009).

Figure 2. Google Earth image of Hovey Lake, Indiana. The bottom, red arrow indicates the DNR office, and the white, top arrow indicates the nearest archaeological site to the west bank of the sampling area. Samples were taken between these two points along the shore.

CHAPTER 2

LITERATURE REVIEW

Range, Environment, and Physiology

In North America, bald cypress is most commonly found in the southeastern quarter of the United States, and in fact, is considered part of the northernmost extension of “southern” floodplains as described by Küchler (1964) (as referenced by Crisman and Whitehead 1974). Its northern boundaries may be found in the swamps of the southern Midwest, southern New England, and as far west as south-central Texas (Figure 3). This species prefers stagnant, detritus-rich fresh waters or environments close to shore and acidic conditions (Little 1971, Wilhite and Toliver 1990, Earle 2008, ODNR 2009, USDA 2009). Although they can grow in the slightly saline water of estuaries, salinity has adverse effects on photosynthesis and stomatal conductance on saplings (Wilhite and Toliver 1990).

Figure 3. North American range of bald cypress (USGS 2010 after Little 1971).

The base of the tree (sometimes submerged) is supported by flared growth of the roots, called buttresses. In some locales, looping aerial roots may protrude from and descend back into the ground or water surface amongst the buttresses. Smaller, vertically reaching root structures, referred to as 'knees' are commonly observed just above the mean water height or just underneath (Wilhite and Toliver 1990, Brand 2000-2001, ODNR 2009), but those who study this phenomenon do not all agree upon their purpose. Wilhite and Toliver (1990) suggest that the knees play a dual role as both respiration apparatus and support for the tree. One hypothesis is the knees catch detritus in the swamp water and allow the tree to use nutrients from this material, while another related mechanism finds young knees growing very close to decaying stumps to obtain those nutrients (Lamborn 1890, Kummer *et al.* 1991). Additionally, when evaluating bald cypress growth habits, Cain (1935) supports the idea that knees seem to develop most effectively during intermediately wet conditions (periods of neither flood nor drought).

The foliage of bald cypress consists of leaf-like needles, which are attached to structures referred to as ‘twiglets’. These structures then grow out from either side of the main twig parallel to each other. This is not to be confused with the closely-related pond cypress (*Taxodium distichum nutans*) which exhibits a spiral configuration of leaves (USDA 1994, ODNR 2009). Unlike most other gymnosperms, this species is deciduous and after these leaves turn rust-brown, they are shed from the tree (Wilhite and Toliver 1990, Jackson 2005, ODNR 2009).

Bald cypress annually bears fruits in the form of round cones, in shades ranging from green to purple in color. When the weather cools in autumn, the cones turn brown and drop triangular seeds. The seeds require a non-flooded patch of soil to germinate; it can be assumed that if there are saplings established, the growing environment has been fairly stable and somewhat dry (Welch 1932). An interesting conjecture was made by Cain (1935) in light of his 1932 investigation of the dwindling bald cypress population of Hovey Lake, Indiana, in comparison to Reelfoot Lake, Tennessee. In order for a bald cypress seed to successfully reach adulthood, the seeds need to be on solid ground and above the water for at least a few days in order to germinate. Next, there must be several subsequent years in which flooding is infrequent or of low magnitude. The plants can survive for a few weeks under the water, but they must be above the water in order to grow and survive to full maturity (Mattoon 1915 as referenced by Cain 1935, Demaree 1932, and Welch 1932). Taking this set of conditions into consideration, and combining it with his understanding of how knees seem to behave, Cain surmised that the occurrence of, "…low, moderately-developed, conical…" buttresses and, "…low, infrequently-developed knees…" may be accepted as an indicator for poor conditions for a successful seed bed. The Hovey Lake site features this type of buttress form.

Flooding and Environmental Effects

As the primary habitat for bald cypress is swampland and still, murky water, the limiting factor, or the force which most influences the growth of the tree (Fritts 1967) will more likely be water over-abundance (Demaree 1932, Welch 1932, Mitsch, *et al.* 1979, Stahle *et al.*, 1985, Stahle *et al.* 1992, Wilhite and Toliver 1990). When considering a swamp-filled lowland, the water level will continuously fluctuate. In addition to oxygen and moisture levels, nutrient and mineral distribution from flood events is also an important factor in ring growth. If the root knees of bald cypress are submerged for a prolonged period of time, the entire organism will be deprived of oxygen and accumulation of ring cells will slow considerably (Mitsch *et al.* 1979). Cain (1935) also reports that if the roots are unable to break from underneath high water, they will not survive. But again, this discussion seems to feed back into the undetermined function of the knees themselves.

The trees are also important parts of a swamp ecosystem because they provide food for such animals as grouse, various waterfowl, squirrels, and further to the southern areas of the range, rodents called nutria. The large buttresses serve as a secure habitat for catfish. It is also not uncommon to find osprey and eagle nests in the tops of the trees (Wilhite and Toliver 1990).

Historical Observations

Around the 1870s, literature full of descriptions of the ridges and swamp-filled lowlands of southwestern Indiana were beginning to be published more and more frequently. These works paint a picture of still, shallow lakes and thickly-forested boundaries populated by great numbers of enormous bald cypress, as well as many other types of towering trees, the great majority of which have since been cleared for lumber and farmland (Wright 1897, DenUyl 1957). Robert Ridgway, an accomplished naturalist based in the Lower Wabash valley, remarked in a 1919 letter to fellow naturalist/botanist Charles C. Deam upon the stark change from a heavily forested land to a prairie-like landscape. He says that as late as 1885, with exception of agricultural land, the region was entirely forested. About 1889 or 1890, people began to drain the swamps. Having recently passed through the area via rail, Deam exclaimed in his letter, "…it would be difficult to find a stick as big as a broom handle in the entire area!" (DenUyl 1957). In the first quarter of the 20th century, naturalists worried that bald cypress might disappear from the region entirely. Bald cypress' foray into the south of Indiana was assumed to have been made possible, "…in the period of flooded streams…" because a more hydroscopic environment better suited the species than many of the native trees (Coulter 1914). Into the 1930s, the concern is not eased. Studies conducted by Demaree (1932), Welch (1932), and Cain (1935) give first-person accounts of the sparse numbers of young bald cypress in southwestern Indiana. The prevailing thought was that extinction of the species was imminent.

Human Use

Economically, bald cypress is highly prized, in part due to its unique grain patterns. The species is known to be very rot-resistant when young. An elevated concentration of a highly water-resistant compound called Cypressene can be found in trees 60 years of age and younger. These levels seem to drop off after this period and the wood becomes increasingly susceptible to rot and disease. The lumber is commonly incorporated into indoor and outdoor building construction such as fencing material, boat planking, cabinets, shingles, furniture, siding, and flooring. Even so, there is a type of fungus (*Stereum taxodi*) that begins to rot very old individuals, beginning at the crown and settling into the heartwood. This imparts a much sought after pattern in the lumber and is called pecky cypress. This form, while not very water-tight, is very durable and desirable for use as construction material. Also environmentally advantageous are the roles of bald cypress in trapping pollutants in water and allowing water from floods to more quickly absorb into the soil (Wilhite and Toliver 1990).

Previous Studies

Bald cypress has a record of longevity in the eastern and southeastern United States and studies have been conducted with a variety of foci in the region. Information from this species lends itself to the fields of archaeology, climatic reconstruction, biochemistry, and geomorphology. The signals found in the rings, when compared to other environmental factors, may tell us much about the landscape's history.

Because of its hardiness and sensitivity to changing hydrologic regimes, bald cypress is an extremely useful species in dendrohydrological studies. One example is the Reelfoot Lake site in Tennessee, where the severe earthquakes of 1811 and 1812 caused a catastrophic water level change. The lake was upset in such a way that the area was inundated and many of the adjacent trees were killed… all except much of the water-loving bald cypresses. Not all of the cypresses were spared, but after the initial high water subsided, it was found that as water levels gradually rose, the trees adapted to this new environmental regime and survived (Cain 1935, Vernon, 1947, Mitsch *et al.* 1979, Stahle *et al.*1992). Young *et al.* (1995) have published findings which indicate that while there may be a temporary increase in ring growth for cypress after a flood event, there seems to be a decrease in ring growth over the long-term.

Of the many bald cypress chronologies compiled over the course of the science of dendrochronology, none have yet exceeded the 1,056-year record out of North Carolina (Stahle *et al.* 1988). The Palmer Drought Severity Index (PDSI) has been reconstructed using a bald cypress master chronology (with living and dead samples) to 1,614 years (Stahle *et al.* 1992). Bald cypress are notoriously problematic to date, due to the irregularity of the rings themselves. When there are a sufficient number of cores, a method employed by Stahle *et al.* (1985) required that first-detrending with negative exponential curves and stiff splines be applied to the raw ring width data. Once detrended and standardized in that fashion, the ring-width indices, by year, were averaged into a, "…robust mean value function chronology…" for each site from which they collected. Second and third order autoregressive models were then applied, leaving only a small amount of variance trend for the residual and the standard chronologies. Finally this last chronology's variance was stabilized using another inflexible spline. It should be noted that this approach was constructed for use in an extremely long chronology and is not typically needed for chronologies less than 200 years; Stahle constructed these statistical parameters in order to assess the damage done to the land after a serious earthquake shook the region of Reelfoot Lake in Tennessee around 1811 and 1812.

CHAPTER 3

METHODS

Field Methods

Data from cores taken by Patrick Munson in the mid-1970s near the study site was made available through Hanover College, via the Glenn Black Laboratory at Indiana University. Newer cores were taken from DNR-owned Hovey Lake and the immediate surrounding shore.

In order to obtain a complete record of climate and hydrology for this region, sampling of live trees is necessary. Using a Swedish increment borer (a hollow metal tube with a spiral drill tip) a small hole was bored to the pith of the tree (Smiley and Stokes 1968). The objective was to extract a complete series of rings from bark to pith for later analysis. Each tree was cored twice, but did no permanent damage to the tree. According to Shigo (1985), to protect themselves from further damage, conifers wounded in this manner first produce enough sap to fill the borehole. After this, the tree forms walls around the damaged area, sealing it off from the healthy cells (Speer 2010). In addition to boring, diameter at breast height was taken.

Three people in a small boat worked to retrieve cores from trees in the water and two people collected samples from near the lake on shore and in shallow water. The attempt was made to core near a relatively uniformly round area of the trunk, as the large buttress-like base of a bald cypress undulates, and may not reveal an accurate ring pattern (Stahle *et al.* 1992). Five people were able to obtain two cores from 21 trees in one day.

Once extracted, each core was stored in a straw and given corresponding provenance (name of collector, GPS coordinates, site, core, number of core, and date of collection). Even-numbered cores refer to those taken from land or very shallow water and the odds indicate those taken from deeper water.

Laboratory Methods

Because these cylinders of wood will mold if they are not dried, it was necessary to partially open the straws and allow the samples to dry out for at least 24 to 48 hours. Cores were taken from the straws and inspected for any twisting of tracheid orientation. Next, white glue was applied to the inside groove of a wooden core mount and the core set inside with the tracheids oriented vertically so that the transverse surface faced to the top. When glue contacts the core, the wood tends to warp and shift out of the transverse-facing position. For this reason, string was wrapped around the core while it set and dried. After a minimum of two hours, the string was removed and the core required resurfacing (Speer 2010). The cores were mechanically sanded with ISO 120-grit (106-125µm), to ISO 320-grit (44.7-47.7µm), to ISO 400-grit (33.5-36.5µm), and finally hand-finished with 30µm, 15µm, and 9µm grit sandpapers, respectively (Orvis and Grissino-Mayer 2002). Sanding is an essential operation, which improves the clarity of the rings and other important diagnostic parts of the rings' anatomy, especially in the case where it is difficult to discern between two rings (Fritts 1975, Orvis and Grissino-Mayer 2002).

The rings of the prepared cores were then counted under a stereoscopic microscope and skeleton plotted on grid paper with five lines per centimeter. Skeleton plotting involves the researcher drawing lines which indicate how wide the ring will be; the smallest widths merit a taller mark and the very widest will either not be plotted or be marked with a “B”. To correct for age-related growth bias, it is common procedure to judge each ring by the three rings surrounding it in either direction. This method of crossdating aids in pattern detection between wide and narrow rings. Another plot, made from the averages of the single-core plots, is called a tree-level master chronology and gives a good representation of how the tree has grown over time (Stokes and Smiley 1968, Speer 2010). To verify my dating results, a second dendrochronologist (Jim Speer) reviewed the dating and made suggestions for improving the dating.

Statistical Methods

After crossdating the samples, I digitally measured the ring widths and entered them into a computer via a Velmex measuring system and the MeasureJ2X program (Speer 2010), at a precision of 0.001mm. The data was imported into COFECHA, statistical software which checks for accuracy of the dating done in the skeleton plotting stage (Grissino-Mayer 2001). After the cores were verified as being accurately dated, the raw ring-width data was analyzed with the computer program ARSTAN. Among other functions, it allows the data to be standardized and statistically builds the master chronology for the site (Cook 1985).

Because trunk width increases as rings are put on, the rings naturally get smaller as they grow out from the tree's center. A transect from pith to bark would show that the rings geometrically decrease in a negatively exponential trend. This function makes it appear as though the rate of growth is declining as the tree ages, which is not necessarily true. To objectively compare these differing ring widths through time, a process called standardization must be used. Three standardization models were applied to the ring widths to determine what standardization technique best removed any age-related growth trends but kept in low frequency signals. The options used were the negative exponential curve, the horizontal mean curve, and a 40-year cubic smoothing spline. Through calculation of regression, the ring widths were compared to Ohio River at Louisville, KY, discharge data from the years 1923-1996 and 2001. The data for 1997-1999 and 2002-2008 were incomplete, and not suitable for use. Ring widths were also compared with temperature, precipitation, and PDSI data from Indiana's Division 7 mean monthly climate data to 1895 (NCDC 2010).

Hydrologic and Climatic Data

Using the gage station on the Ohio River at Louisville, Kentucky (about 230 miles upstream from Hovey Lake), monthly discharge (in cubic feet) was obtained. Because long-range data is unavailable from stations more local to Hovey Lake, the Louisville location was deemed most proximate on which to base monthly flood information. Indiana Division 7 monthly mean temperatures, monthly mean measures of the Palmer Drought Severity Index (PDSI), and monthly mean precipitation data from the National Climatic Data Center (NCDC) were gathered.

Monthly temperature and precipitiation data shows that precipitiation starts to decline as temperatures rise to peak in June and July (Figure 4). This is likely to produce water stress in the trees at this time of year. Preciciptiation continues to decline into the fall, but decreasing temperatures may ameleorate any drought effect at that time.

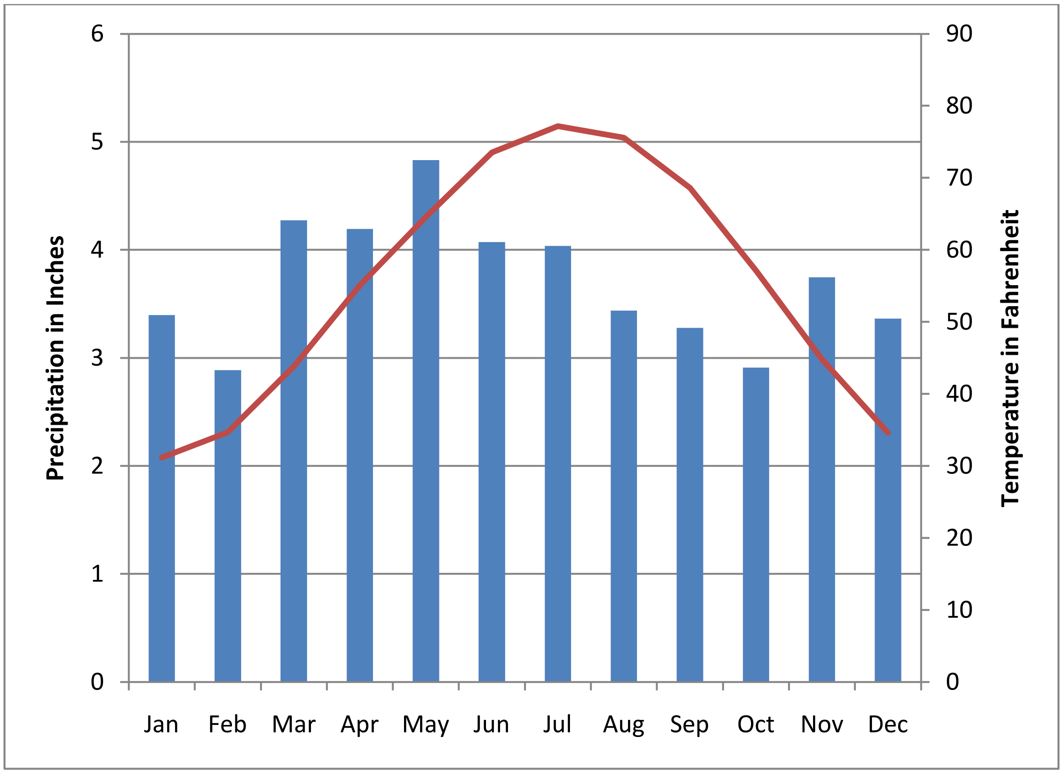

Figure 4. Indiana's Division 7 climograph. This compares monthly averages of temperature versus monthly average precipitation from 1895 to 2008 (NCDC 2010).

GIS Methods

Maps were made to compare the series intercorrelation and mean sensitivity of all bald cypress chronologies in the International Tree-Ring Databank (ITRDB). This is an international databank where researchers voluntarily contribute their final tree-ring chronologies from around the world. There are over 3,000 chronologies stored in the databank, including 32 bald cypress chronologies that were used in these analyses. Another map was made to compare the correlation of the Hovey Lake master chronology to these other chronologies throughout the range of the species. Sites were selected based on inclusion of a master COFECHA bald cypress chronology in the ITRDB. To plot the site points, the latitude and longitude were collected from the ITRDB and converted to decimal degree format. This location along with series intercorrelation (how well each core in the stand agrees with one another), mean sensitivity (how varied the tree-ring widths are along the core- more complacent implies less variation and more sensitive implies more variation), and the correlations of the standard negative exponential chronologies were included in an Excel spreadsheet for each site. After this, the Excel file was imported into ArcGIS 10.0 and the points appeared on a base topographic layer and a base political boundary map of the United States. The values for each of the sites were called upon in three separate maps and were made available for comparison with use of graduated symbols of differing colors for each category break.

CHAPTER 4

RESULTS

Summary Statistics

Of the 21 trees sampled and 42 cores taken, only 23 cores from 12 trees were acceptable for analysis. Many of these trees were too young (<20 years) and therefore did not have enough time depth for time series analysis or to make a substantial contribution to the master chronology. These trees were not old enough to document natural growth or as a comparison before and after the dam was built. Other cores were taken from locations on the tree which were damaged or too close to a buttress curve. Several cores, after much comparison to the master chronology, were deemed to be too different in ring pattern to reflect a common stand-level signal and were excluded. The cores which were sampled from the area, around the mid-1970s, were also unacceptable for analysis. These cores have problems such as pockets of pitch, rot, missing wood, and unsuitable core preparation. Some of the same problems as the newer samples, such as error in borer placement and poor correlation to the master (likely meaning they belong to another stand) were also responsible.

When looking at the locations of the samples, the majority of the nearshore samples were too young to include. However, this seems to indicate a time of recovering population for the bald cypress. There is a gap in individual sprouting years from 1941 to 1983, with the average onshore and nearshore samples establishing near the mid to late 1980s. This could mean a normalizing shoreline and potential for recovery from the the dam flooding of 1975.

The final summary statistics for COFECHA include a 0.530 series intercorrelation and a 0.489 mean sensitivity out of 134 years and 1895 rings. This indicates a good stand-level signal and strong crossdating, while the mean sensitivity is extremely high which led to many dating difficulties such as false and micro rings. In the master chronology, a sharp increase in ring width was observed after 1974 (reflecting the dam construction of 1975), followed by a sharp decrease in ring width through much of the 1980s (Figure 4a). The Expressed Population Signal (EPS) is a curve representing the signal to noise ratio that required a good enough sample depth to reflect the common signal for the site. The EPS indicates that an adequate sample depth providing a good signal to noise ratio begins in the 1930s, so I truncated the chronology to this starting point (Speer 2011).

Standardization Results

I used a negative exponential, a horizontal line fit, and a 40-year cubic smoothing spline to detrend the series and compared these standardization techniques in the development of the final chronologies (Figure 4). The chronologies were very similar, but I found that the negative exponential standardization curve was the best fit to accentuate the climate response (Figure 4b). The horizontal line fit was the best to show the effect of the dam on tree growth (Figure 4c). I decided not to use the 40-year smoothing spline, because although all three standardizations were very similar, this line over-fit to the post-dam years.

Climate Response

Dam construction in 1975 overwhelmed the climate response for the years subsequent. Very few monthly climate variables were significant when comparing the entire data set, but June precipitation, June temperature, and summer PDSI weresignificant and highly correlated for the 1930-1974 time period (Figures 5, 6, and 7). Annual aggregates such as annual precipitation, summer PDSI, and annual PDSI also were significant variables, but were not as high as June on its own. When using the complete data set, the overall correlations were 0.2 lower than when I truncated the data to 1974, prior to dam construction (Appendices A and B). Discharge was not found to be significant at the 0.01 level and is not considered a driving force in ring-width changes.

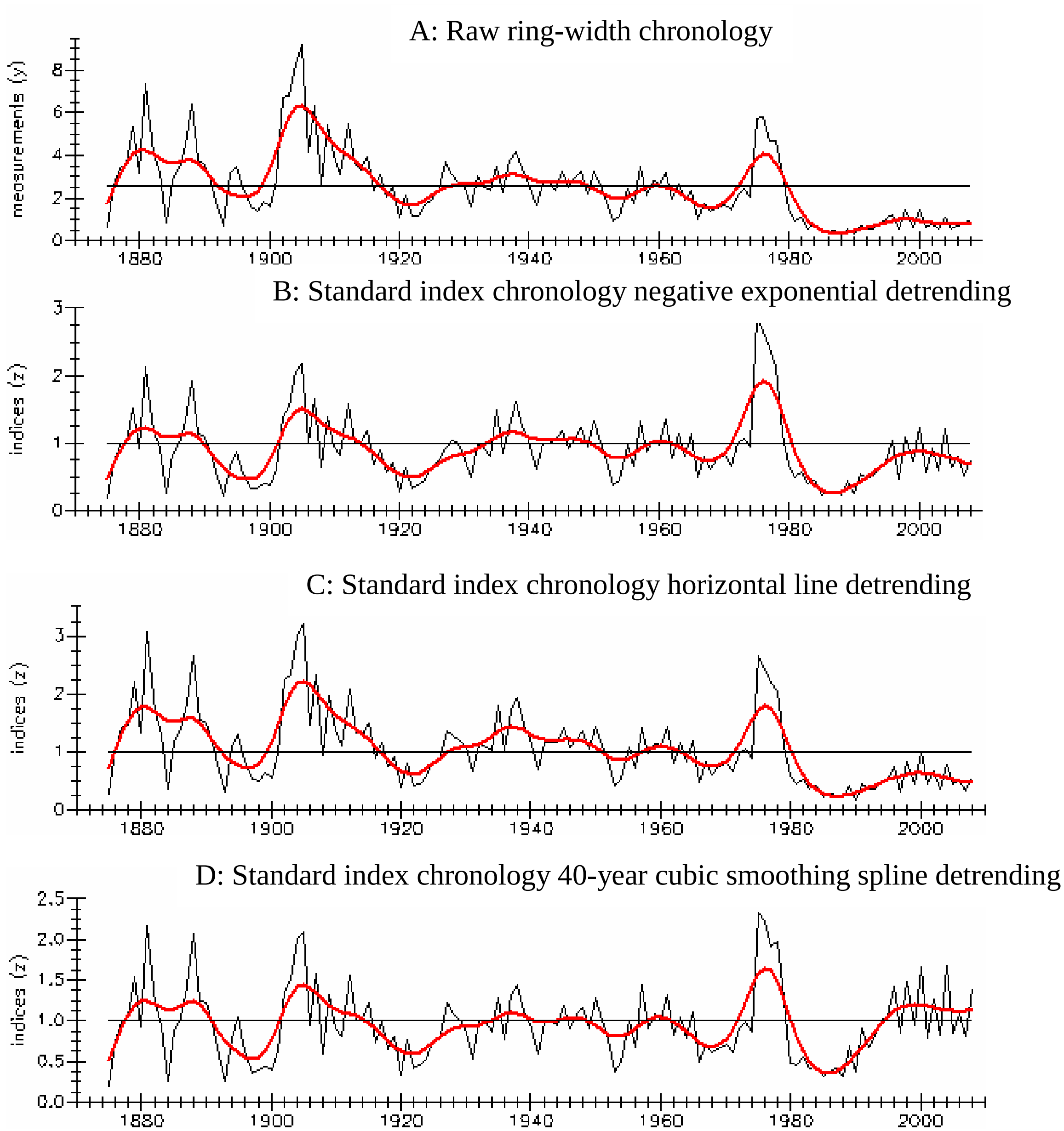

Figure 5. Standardized ARSTAN chronologies.

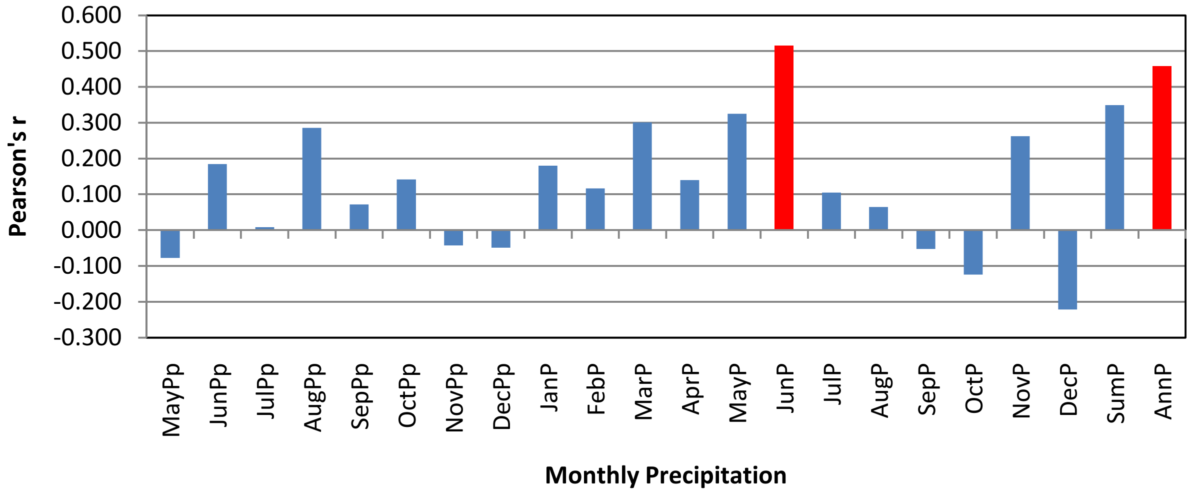

Figure 6: Precipitation response with standard negative exponential standardization master. Red bars are significant at the two-tailed 0.01 level. P in the x-axis labels stands for precipitation and p is for prior year variables.

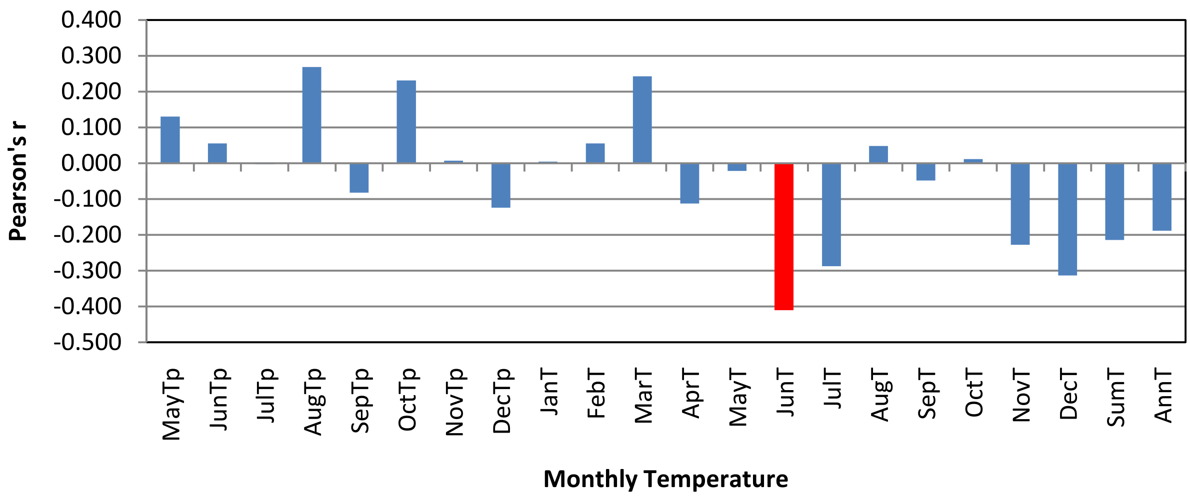

Figure 7: Temperature response with standard negative exponential standardation master. Red bars are significant at the two-tailed 0.01 level. T in the x-axis labels stands for temperature and p is for prior year variables.

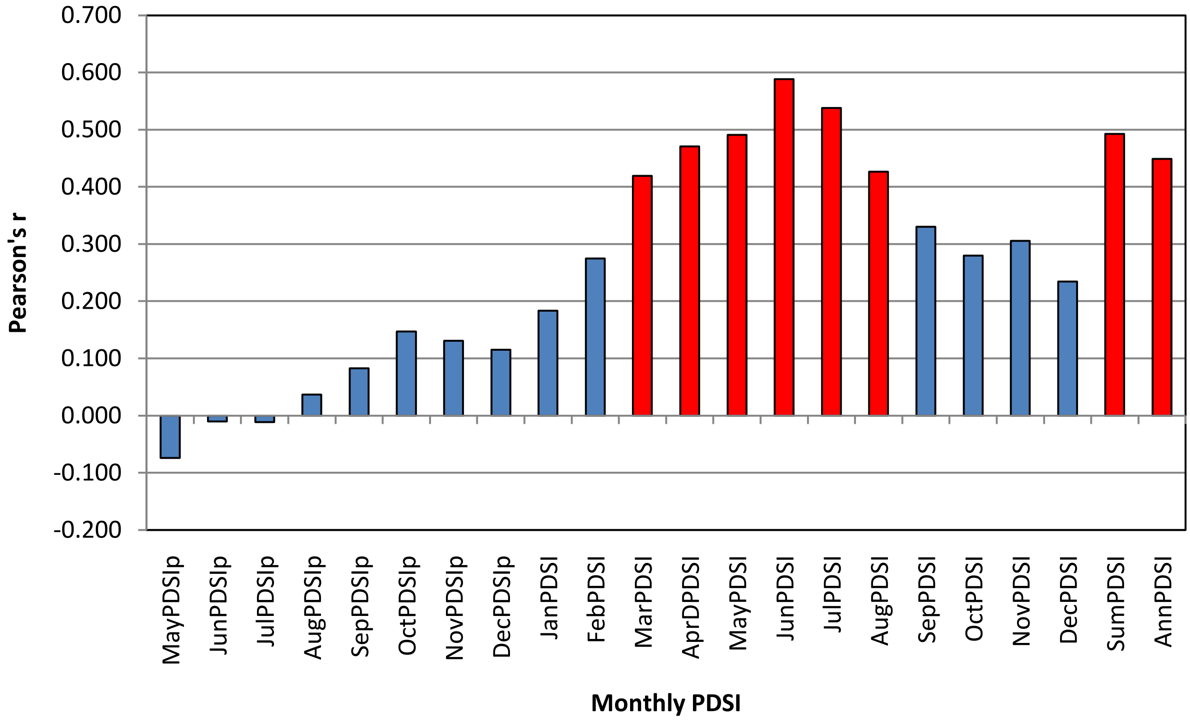

Figure 8: PDSI response with standard negative exponential standardization master.

Red bars are significant at the two-tailed 0.01 level. In the x-axis labels p stands for prior year variables.

June PDSI was the most significant climate response when compared to my master chronology. When conducting a simple linear regression analysis, I found that 35% of the variance was explained by this one monthly variable (Figure 8). This could be used as a model for reconstructing June PDSI once this bald cypress chronology is extended back through time.

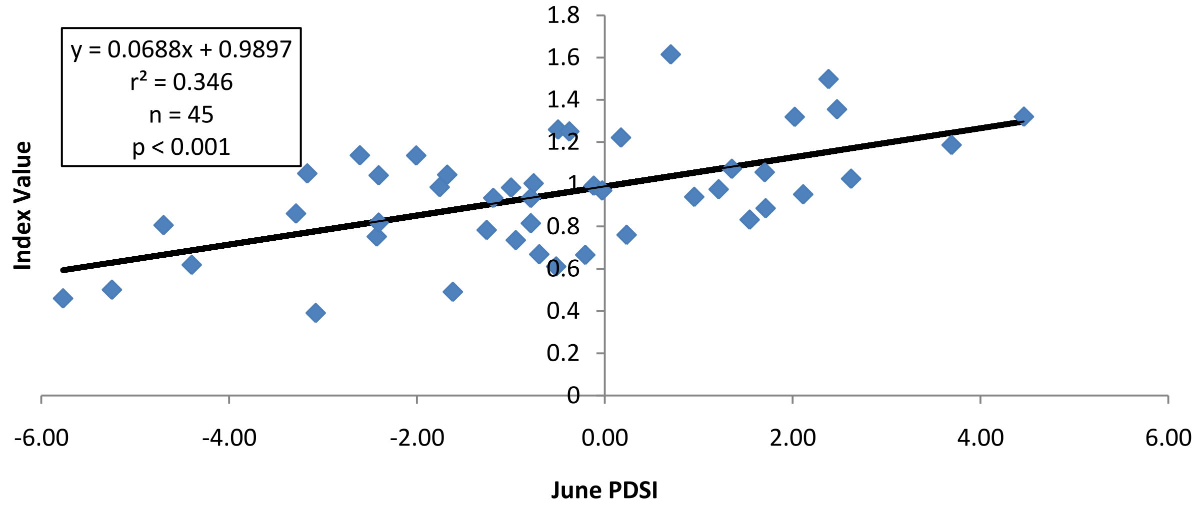

Figure 9: Response of the standard chronology with a negative exponential standardization to June PDSI from 1930-1974.

Intersite Map Comparison

The highest correlated ITRDB bald cypress chronologies to Hovey Lake belong to those sites that are nearest to Hovey Lake (Figure 9). It is interesting that the Chickahominy site in Virginia also correlates relatively well even though it is very spatially distant and has a very different microclimate, given its proximity to the ocean. The series intercorrelation of the sites are less similarily clumped than the correlation map. The series intercorrelation (a measure of site-level signal strength) seems to be higher in the center of the range for bald cypress with Arkansas, North Carolina, and Georgia showing the highest values (Figure 10). Analysis of the mean sensitivity (a measure of variability of growth) across all sites tends to increase in the southeast which is also interpreted as a central location for the species range (Figure 11).

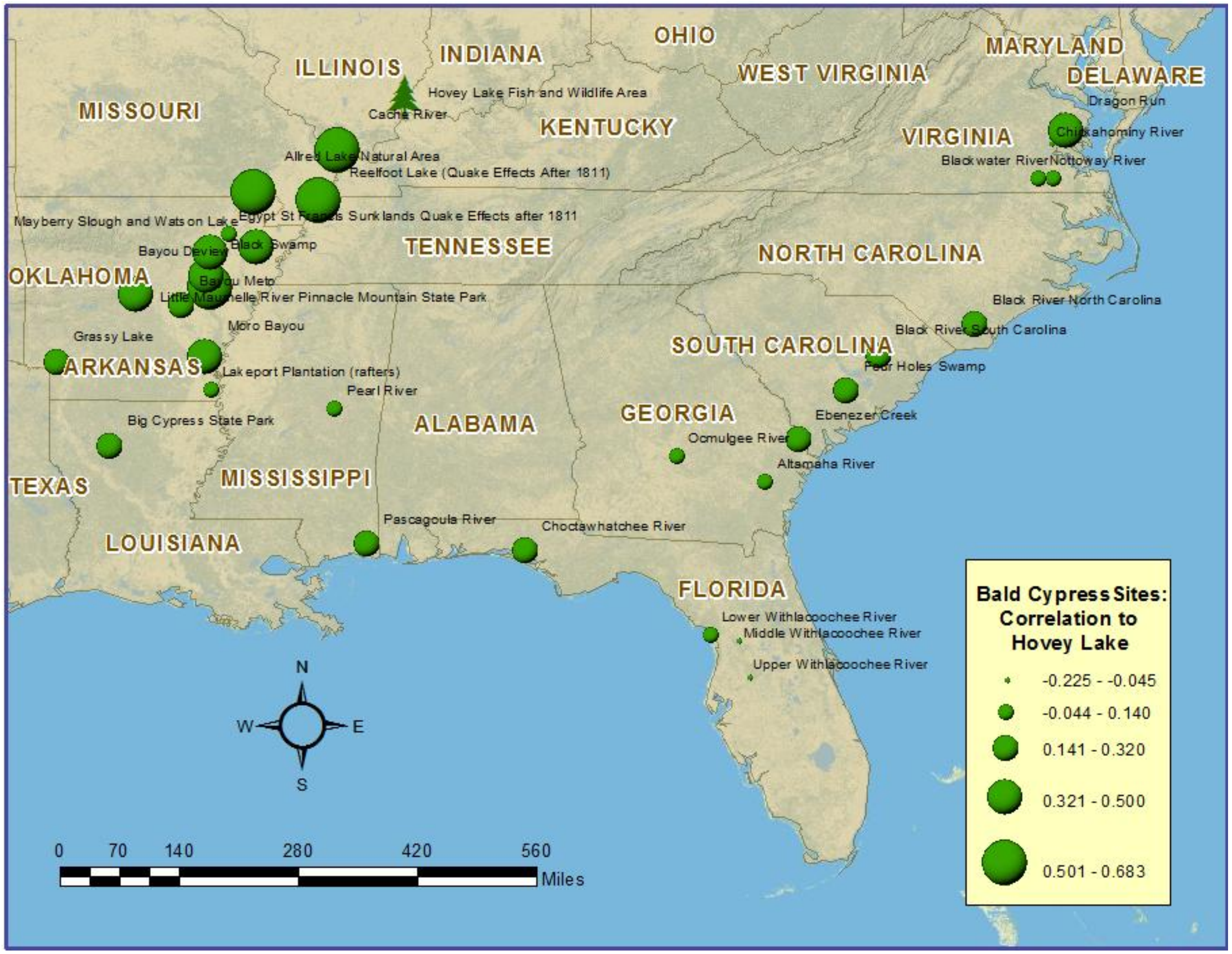

Figure 10. Comparisons of Hovey Lake's standard negative exponential statistic to all other ITRDB-recorded bald cypress sites (USA Topographic Maps 2011).

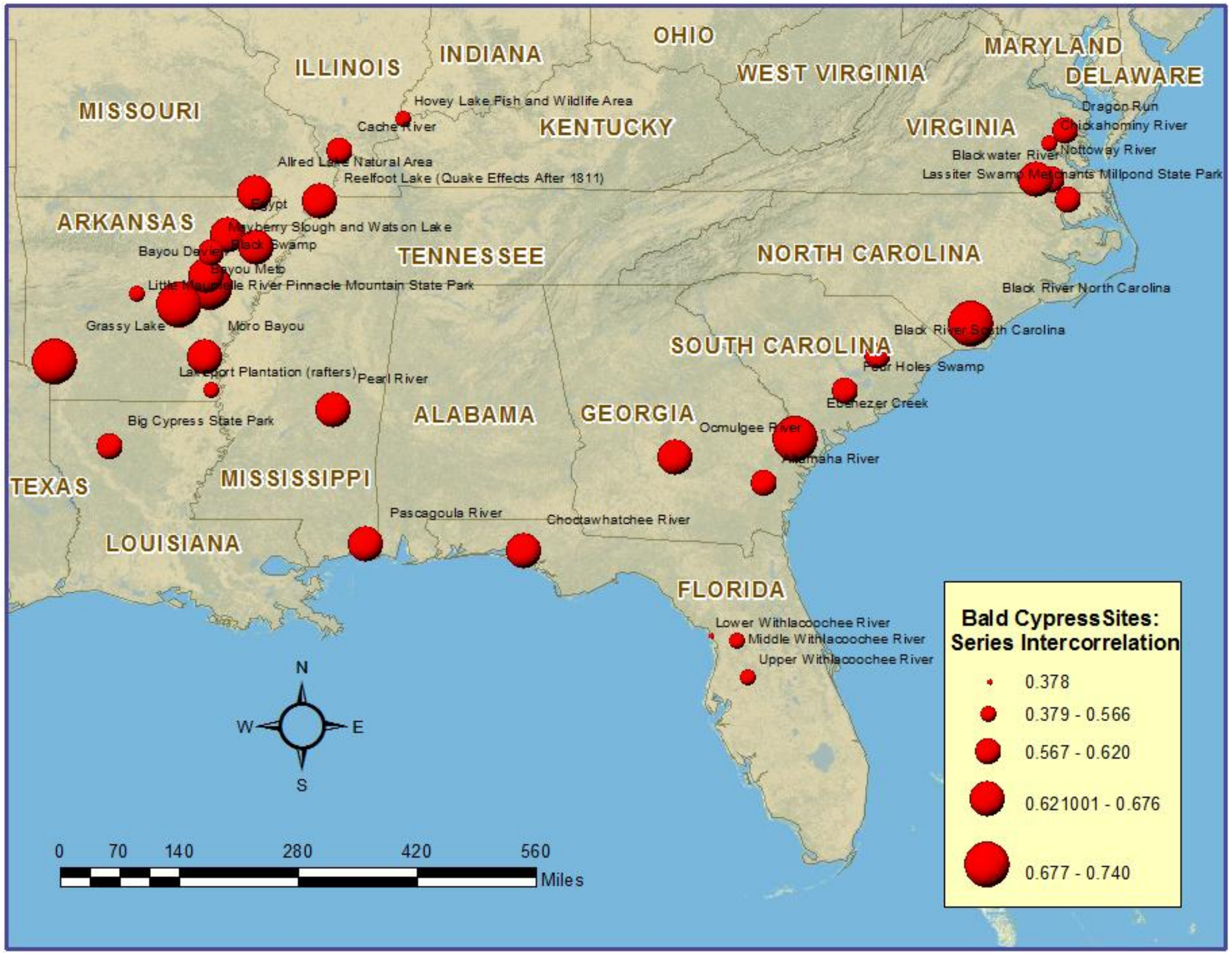

Figure 11. Comparison between Hovey Lake's series intercorrelations and those of all ITRDB-recorded bald cypress sites (USA Topographic Maps 2011).

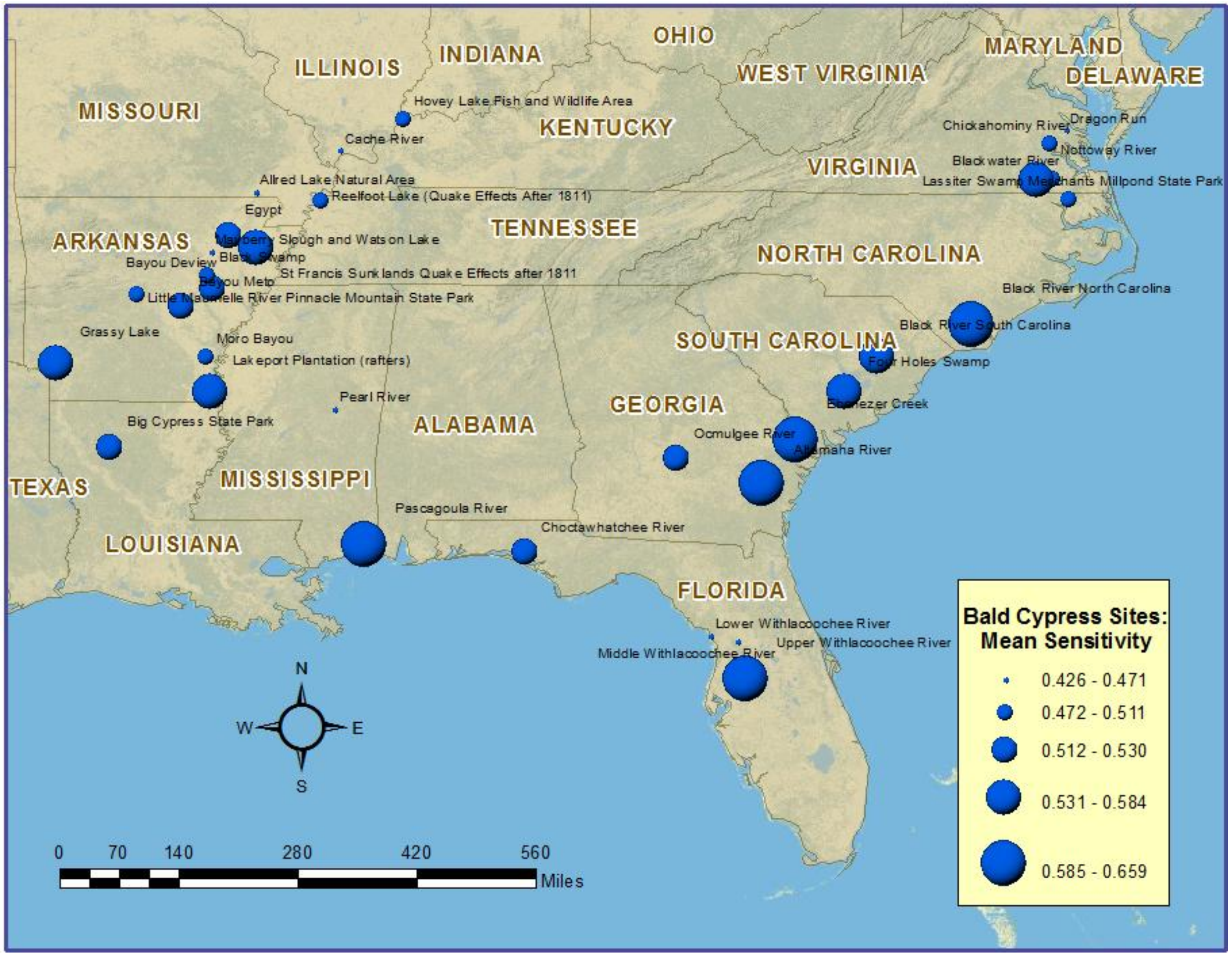

Figure 12. Comparison between Hovey Lake's mean sensitivity and those of all ITRDB-recorded bald cypress sites (USA Topographic Maps 2011).

CHAPTER 5

DISCUSSION

The dating of these samples was extemely difficult. When sampling bald cypress, the researcher underestimated the effect of the root buttresses. It likely would have been more conducive to less errors, had the samples been taken higher above the buttresses (Stahle *et al.* 1992). This may have marginally reduced the occurrence of missing, false, and micro rings. The oldest core I dated went back to 1855, but I had to cut it to 1875 in order for it to date well with the rest of my cores. Most of the cores were cut to 1925, and a few were cut to even later, the latest at 1955. This ended up removing 75 years of rings that in the future could potentially be used to develop a local climate reconstruction. Potentially, the bald cypress of this area could result in a relatively long chronology.

The cores taken in the 1970s, although not used in the final thesis, were briefly examined. The longest of those seemed to reach into the early 1700s, if the outside dates are accurate. With a greater sample depth, these older cores could be more reliably cross-dated and the chronology could reach back a considerable distance. During my fieldwork around Hovey Lake, I visited Cypress Slough in Posey County that is managed by the Department of Natural Resources. This looks like a potential place to sample very old bald cypress and may have been the location from which the Munson cores were taken. As earlier mentioned, there are highly specific conditions which bald cypress require to grow to maturity (Welch 1931), and to thrive afterward (Wilhite and Toliver 1990).

I was able to demonstrate through ring counts that there exists potential for a chronology extending back into the 1700s, but more work needs to be done to achieve that goal. If I were to build a more complex study based on this research, the number of sampling sites would first have to be increased. Analysis of multiple stands throughout the area would strengthen the area's bald cypress chronology. More work needs to be completed, such as searching the archives at the Glenn Black Laboratory and interviewing the Munsons to find any missing cores and or notes from the sampling in the 1970s. If there is to be another analysis of river discharge, it may be useful to have a stronger chronology in terms of many more trees and stands. An even greater improvement may lie in a different study site altogether, which lies closer to the gage station where the discharge data has been collected. Additionally, analysis of flood stage data may be useful to document significant years of flooding.

The Hovey Lake site is the northernmost bald cypress chronology in the Midwestern U.S., which may have contributed to its difficulty in dating. This can be a useful site in the future with much more work on the chronology because of its unique location of native bald cypress trees. The selection of this site is ideal, as the bald cypress are living at the edge of their ecological amplitude (where they should be most sensitive and thus will more easily reveal a limiting factor which will then allow for a clearer climate response to be gleaned) (Stahle *et al.* 1985a, Speer 2010). The nearer bald cypress sites make sense to be highly correlated with Hovey Lake, as they likely share a similar climate and also ecological and hydrologic regimes (see Figure 9). The high correlation in Virginia seems to only have latitude in common with Hovey Lake. The further away the sites are located, the less they seem to be correlated with the Hovey Lake site. Series intercorrelation, in comparison to Hovey Lake, points to a stronger site-level pattern in the chronologies. The strongest of those appear in the middle of the species' range.

This may mean there are less harmful limiting factors in a preferred environment or the species is given to a more homogenously ideal growing environment. The series intercorrelation of the sites are less similarily clumped than the correlation map. The series intercorrelation (a measure of site-level signal strength) seems to be higher in the center of the range for bald cypress with Arkansas, North Carolina, and Georgia showing the highest values. These results for series intercorrelation and mean sensitivity are counter to the theory of ecological amplitude and suggest that we do not really understand how species range effects site-level signal strength and sensitivity at least for bald cypress. The range for this species (Figure 1) is pretty complex which may contribute to this diversion from the basic concepts of ecological amplitude. In terms of similarity of sites regarding mean sensitivity, the trend seems to be that the further towards the southeast in the range, the less complacent are the tree rings. Less complacency indicates more stressful conditions for the tree.

I stated in my first hypothesis that tree growth would increase with greater flow as measured by Ohio River discharge. Although no monthly variables were significant at the 99% confidence level, Winter (January through April) and Summer (June and July) discharge does have a significant positive correlation with tree growth at the 90% confidence level. This is a weaker response than the other climate data examined in this study, which may be due to the distance of my field site from the Ohio River gage location. I would recommend future studies to choose sites that are more proximate to the river sites and the specific sites where discharge measurements have been taken.The 90% confidence interval is often used in ecology when many competing factors affect the response in natural systems. In dendrochronology we often have a large enough sample for analysis (over 100 years with climate data back to 1895). In this analysis, our discharge data was reduced in length, resulting in weaker correlations which did not meet our test for significance. The consistency of the winter and summer discharge response suggests that this may be a real pattern that could be pursued in future studies.

This chronology had a strong and very simple climate response that was supported through all of the climate variables that I tested in this study. A positive correlation with June precipitation was the strongest precipitation response. A negative correlation with June temperature suggests that moisture stress due to high temperatures in the middle of the summer greatly reduce bald cypress growth at this site. These responses are supported by the strongest individual response of June PDSI which is a combination of precipitation and temperature that relate to moisture stress in these trees. These results support my second hypothesis that the trees would be most strongly responding to PDSI.

This drought response was consistent and strong, but only prior to dam construction. Since the construction of the dam and inundation with water, there is little climate response in the wood since 1975. The dam’s construction seemed to have greatly increased growth of the bald cypress at the beginning as the water brought in fresh nutrients and removed competition from less water-tolerant species. But with the long-term residence of the water in Hovey Lake, even the bald cypress tree health has declined. I have documented over 20 years of ring growth suppression in these trees due to water retention behind the dam. These trees still have not recovered to their normal growth, defined as the 1875-1974 average growth. It is likely that the bald cypress trees that remain in deep water will either continue to grow at a very slow rate or die from a lack of oxygen to their roots, although our cores from fast growing young bald cypress around the edge of the lake suggests that this species will continue with healthy cypress trees at this new location. The decline in growth of the older trees would seem to support my third hypothesis about the decline in growth of bald cypress in Indiana, but the young vibrant trees around the edge of the lake demonstrate that the reduction in my chronology is due to the disturbance of the dam construction. I can therefore reject my third hypothesis because many of the young trees around the edge of the lake showed fast growth which is likely to ensure the survivorship of bald cypress in southwestern Indiana.

CHAPTER 6

CONCLUSION

Bald cypress is a water-loving tree, and at Hovey Lake, the species is situated at a far, dry margin of its range. There seems to be sufficient evidence that drought is the principle factor which influences yearly ring growth. Due to the bald cypress' unique physiology, knack for adaptation to a host of hydrologic conditions, and decay resistance, it has been useful in many scientific, ecological, and commercial applications across the eastern United States. From observations of the individual trees at Hovey Lake, this species does not seem to be declining in Indiana. Because the Ohio River discharge signal could not easily be differentiated from the damming event, further studies using the species may be best served by examining the hydrology aspect, as well as survival rate over time. To test against a strong dam-led disturbance signal, sites which do not have dams should also be sampled. Because this chronology is the northernmost chronology in the Midwest, investigators who need a more localized proxy record for climate will benefit from the work presented here. Findings from this work may be of aid in dating geomorphic features and archaeological sites. It may also lend support to those who study the physiology of bald cypress or similar swamp species, as well as providing insight as to how climactic patterns or discharge-related processes may affect the growth and distribution of bald cypress.

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APPENDIX A: CORRELATION MATRIX: 1930-1974

This correlation matrix shows the relationship between all of the chronologies (with different standardization techniques) developed at Hovey Lake and 86 monthly climate variables including the current year's climate and eight lagged months of discharge, precipitation, temperature, and PDSI. Compared to the years which span 1930-2008 (Appendix B), this provides another view as to the normal signal of Hovey Lake's bald cypress growth before the dam was built.

Red filled cells indicate variables which have met or exceeded the significance value of 0.392 (n = 40, p = 0.01), and yellow filled cells indicate variables which have met or were less than the significance value of -0.392.

PDSI: Palmer Drought Severity Index

CFS: Cubic Feet per Second: a common unit of discharge

P: Precipatation for a given month.

T: Temperature for a given month

p: prior month's reading

raw: unstandardized ring-width chronology in ARSTAN

std: standard ARSTAN chronology (based on user-entered parameters, still retains autocorrelation) res: residual ARSTAN chronology (from which autocorrelation is removed)

ars: ARSTAN chronology (autocorrelation is removed, then modeled to how the stand should act as if it were autocorrelated)

ne: negative exponential curve standardization (assumes the same amount of cells will be put on the tree each year, while the trunk width keeps increasing)

hmc: horizontal mean curve standardization (average horizontal line)

40: 40 year smoothing spline standardization (takes out half the variance after 40 years, filters extraneous noise)

	rawne	stdne	resne	arsne	rawhmc	stdhmc	reshmc	arshmc	raw40	std40	res40	ars40
MayCFSp	-0.125	-0.166	-0.250	-0.218	-0.118	-0.163	-0.248	-0.242	-0.125	-0.128	-0.221	-0.151
JuneCFSp	0.153	0.128	-0.020	0.153	0.162	0.067	-0.034	0.114	0.153	0.136	-0.019	0.166
JulyCFSp	0.268	0.242	0.023	0.291	0.265	0.185	-0.004	0.227	0.268	0.277	0.055	0.296
AugCFSp	0.237	0.235	0.020	0.129	0.243	0.194	0.014	0.128	0.237	0.222	0.041	0.196
SepCFSp	0.164	0.149	0.032	0.100	0.171	0.102	0.032	0.087	0.164	0.142	0.066	0.139
OctCFSp	0.115	0.080	0.278	0.082	0.117	0.099	0.264	0.054	0.115	0.121	0.290	0.088
NovCFSp	0.059	0.037	0.059	0.102	0.058	0.040	0.032	0.041	0.059	0.040	0.025	0.026
DecCFSp	0.012	0.045	0.062	0.106	0.017	-0.015	0.045	0.012	0.012	0.064	0.061	0.059
JanCFS	0.326	0.240	0.260	0.320	0.325	0.301	0.292	0.337	0.326	0.325	0.217	0.297
FebCFS	0.327	0.292	0.164	0.319	0.327	0.276	0.152	0.275	0.327	0.322	0.188	0.338
MarCFS	0.185	0.260	0.144	0.151	0.188	0.211	0.115	0.142	0.185	0.217	0.184	0.174
AprCFS	0.287	0.369	0.104	0.317	0.284	0.294	0.059	0.279	0.287	0.315	0.177	0.309
MayCFS	-0.006	0.093	0.174	0.022	-0.012	0.051	0.155	-0.018	-0.006	0.064	0.155	0.020
JuneCFS	0.221	0.257	0.196	0.279	0.226	0.213	0.170	0.229	0.221	0.227	0.197	0.222
JulyCFS	0.296	0.330	0.325	0.345	0.297	0.292	0.326	0.319	0.296	0.295	0.339	0.313
AugCFS	0.132	0.193	0.193	0.077	0.134	0.210	0.193	0.123	0.132	0.127	0.183	0.079
SepCFS	0.075	0.184	0.114	0.145	0.075	0.139	0.094	0.094	0.075	0.129	0.108	0.100
OctCFS	-0.134	-0.078	0.183	-0.080	-0.125	-0.105	0.160	-0.139	-0.134	-0.087	0.133	-0.087
NovCFS	0.123	0.218	0.382	0.251	0.131	0.130	0.340	0.157	0.123	0.192	0.355	0.193
DecCFS	0.016	0.129	0.207	0.157	0.015	0.017	0.140	0.016	0.016	0.101	0.182	0.127
MayPp	-0.018	-0.077	-0.285	-0.117	-0.006	-0.054	-0.294	-0.114	-0.018	-0.035	-0.234	-0.047
JunPp	0.117	0.184	-0.154	0.165	0.121	0.128	-0.194	0.103	0.117	0.138	-0.131	0.151
JulPp	-0.065	0.008	-0.084	0.064	-0.059	-0.071	-0.129	-0.071	-0.065	-0.002	-0.110	0.048
AugPp	0.275	0.286	0.213	0.195	0.272	0.243	0.233	0.224	0.275	0.265	0.254	0.219
SepPp	0.099	0.071	0.036	-0.062	0.086	0.107	0.066	0.014	0.099	0.069	0.053	0.012
OctPp	0.189	0.142	0.347	0.170	0.185	0.177	0.350	0.206	0.189	0.157	0.351	0.157
NovPp	-0.021	-0.043	-0.096	0.037	-0.024	-0.067	-0.091	-0.011	-0.021	-0.037	-0.161	-0.015
DecPp	-0.106	-0.049	0.145	-0.005	-0.112	-0.084	0.143	-0.057	-0.106	-0.011	0.119	-0.030
JanP	0.276	0.180	0.204	0.267	0.270	0.257	0.241	0.299	0.276	0.248	0.164	0.268
FebP	0.113	0.117	0.002	0.130	0.116	0.095	-0.036	0.065	0.113	0.158	0.061	0.176
MarP	0.210	0.301	0.214	0.237	0.209	0.248	0.200	0.224	0.210	0.235	0.247	0.195
AprP	0.050	0.140	0.169	0.143	0.051	0.071	0.120	0.078	0.050	0.103	0.180	0.101
MayP	0.250	0.325	0.343	0.250	0.242	0.266	0.322	0.223	0.250	0.336	0.349	0.280
JunP	0.476	0.516	0.455	0.518	0.489	0.479	0.445	0.486	0.476	0.503	0.481	0.509
JulP	0.026	0.105	0.145	0.080	0.032	0.028	0.111	-0.002	0.026	0.090	0.163	0.128
AugP	0.027	0.064	-0.046	0.049	0.027	0.031	-0.018	0.023	0.027	0.070	-0.049	0.067
SepP	0.033	-0.053	-0.017	-0.120	0.025	-0.008	0.049	-0.043	0.033	0.036	0.049	-0.024
OctP	-0.068	-0.124	0.137	-0.087	-0.074	-0.079	0.177	-0.031	-0.068	-0.115	0.054	-0.088
NovP	0.222	0.262	0.295	0.235	0.225	0.189	0.250	0.159	0.222	0.256	0.344	0.252
DecP	-0.211	-0.221	-0.074	-0.184	-0.217	-0.277	-0.067	-0.237	-0.211	-0.186	-0.074	-0.158
SumP	0.308	0.349	0.418	0.288	0.307	0.300	0.440	0.273	0.308	0.382	0.432	0.357
AnnP	0.413	0.457	0.501	0.439	0.410	0.394	0.497	0.383	0.413	0.490	0.530	0.477
MayTp	0.127	0.130	0.049	0.135	0.131	0.170	0.041	0.142	0.127	0.133	0.057	0.120
JunTp	0.031	0.055	0.176	-0.051	0.034	0.107	0.234	0.067	0.031	0.048	0.194	-0.031

JulTp	0.106	-0.002	0.100	-0.100	0.096	0.144	0.168	0.077	0.106	0.004	0.055	-0.058
AugTp	0.351	0.269	0.206	0.222	0.348	0.371	0.236	0.325	0.351	0.259	0.199	0.239
SepTp	0.036	-0.083	-0.015	-0.035	0.035	-0.015	0.041	0.040	0.036	-0.025	0.001	-0.020
OctTp	0.245	0.231	0.196	0.249	0.250	0.174	0.189	0.233	0.245	0.230	0.212	0.222
NovTp	-0.054	0.007	0.018	-0.046	-0.053	-0.057	0.060	-0.038	-0.054	-0.033	-0.009	-0.017
DecTp	-0.081	-0.124	0.052	-0.050	-0.081	-0.107	0.082	-0.030	-0.081	-0.057	0.055	-0.042
JanT	0.059	0.005	0.041	-0.025	0.049	0.049	0.092	0.050	0.059	0.039	0.005	0.004
FebT	0.120	0.056	0.112	0.046	0.108	0.101	0.147	0.070	0.120	0.100	0.126	0.073
MarT	0.160	0.243	0.093	0.111	0.165	0.206	0.081	0.112	0.160	0.157	0.103	0.117
AprT	-0.096	-0.113	0.243	-0.071	-0.095	-0.129	0.238	-0.112	-0.096	-0.078	0.219	-0.054
MayT	-0.005	-0.022	-0.124	0.003	-0.003	-0.018	-0.124	0.023	-0.005	0.010	-0.118	0.013
JunT	-0.283	-0.410	-0.442	-0.416	-0.289	-0.316	-0.393	-0.292	-0.283	-0.365	-0.452	-0.392
JulT	-0.170	-0.288	-0.292	-0.417	-0.178	-0.150	-0.220	-0.219	-0.170	-0.264	-0.262	-0.355
AugT	0.190	0.048	0.045	-0.006	0.191	0.178	0.098	0.150	0.190	0.086	0.079	0.018
SepT	0.017	-0.048	0.026	-0.101	0.000	0.008	0.047	-0.029	0.017	-0.050	0.073	-0.075
OctT	-0.005	0.012	-0.116	0.011	-0.002	-0.004	-0.123	0.026	-0.005	-0.058	-0.129	-0.005
NovT	-0.260	-0.228	-0.195	-0.189	-0.262	-0.221	-0.212	-0.216	-0.260	-0.232	-0.173	-0.217
DecT	-0.279	-0.314	-0.293	-0.287	-0.289	-0.315	-0.286	-0.282	-0.279	-0.298	-0.294	-0.254
SumT	-0.081	-0.215	-0.283	-0.277	-0.089	-0.097	-0.229	-0.103	-0.081	-0.198	-0.255	-0.239
AnnT	-0.093	-0.188	-0.169	-0.259	-0.106	-0.105	-0.115	-0.136	-0.093	-0.172	-0.158	-0.209
MayPDSIp	-0.069	-0.074	-0.420	-0.066	-0.059	-0.098	-0.465	-0.152	-0.069	-0.051	-0.381	-0.040
JunPDSIp	-0.038	-0.010	-0.365	0.029	-0.031	-0.066	-0.426	-0.096	-0.038	-0.012	-0.336	0.022
JulPDSIp	-0.056	-0.011	-0.335	0.069	-0.049	-0.088	-0.406	-0.097	-0.056	-0.009	-0.316	0.042
AugPDSIp	0.018	0.037	-0.249	0.075	0.018	-0.046	-0.284	-0.041	0.018	0.043	-0.213	0.077
SepPDSIp	0.059	0.083	-0.165	0.065	0.056	0.015	-0.189	-0.018	0.059	0.078	-0.128	0.091
OctPDSIp	0.164	0.147	0.003	0.168	0.160	0.126	-0.012	0.110	0.164	0.162	0.017	0.175
NovPDSIp	0.143	0.131	-0.001	0.168	0.138	0.101	-0.018	0.100	0.143	0.141	-0.002	0.156
DecPDSIp	0.107	0.115	0.040	0.180	0.101	0.075	0.020	0.097	0.107	0.131	0.029	0.143
JanPDSI	0.210	0.184	0.090	0.258	0.203	0.177	0.088	0.207	0.210	0.214	0.066	0.232
FebPDSI	0.251	0.275	0.139	0.299	0.250	0.219	0.113	0.211	0.251	0.306	0.166	0.318
MarPDSI	0.346	0.419	0.287	0.394	0.344	0.357	0.260	0.333	0.346	0.406	0.314	0.377
AprPDSI	0.382	0.471	0.359	0.438	0.381	0.383	0.319	0.360	0.382	0.464	0.399	0.439
MayPDSI	0.391	0.491	0.415	0.442	0.387	0.400	0.377	0.365	0.391	0.489	0.455	0.448
JunPDSI	0.472	0.588	0.500	0.558	0.478	0.486	0.452	0.447	0.472	0.565	0.531	0.555
JulPDSI	0.425	0.538	0.475	0.535	0.433	0.419	0.420	0.394	0.425	0.531	0.509	0.551
AugPDSI	0.337	0.426	0.363	0.431	0.337	0.320	0.331	0.307	0.337	0.426	0.397	0.454
SepPDSI	0.283	0.330	0.297	0.327	0.282	0.255	0.286	0.237	0.283	0.357	0.334	0.366
OctPDSI	0.247	0.280	0.278	0.247	0.245	0.224	0.280	0.192	0.247	0.296	0.298	0.298
NovPDSI	0.262	0.305	0.328	0.277	0.262	0.236	0.321	0.208	0.262	0.317	0.349	0.321
DecPDSI	0.181	0.235	0.309	0.234	0.180	0.147	0.294	0.144	0.181	0.247	0.308	0.272
SumPDSI	0.400	0.492	0.432	0.472	0.402	0.391	0.398	0.360	0.400	0.495	0.469	0.497
AnnPDSI	0.376	0.449	0.380	0.441	0.375	0.358	0.350	0.338	0.376	0.458	0.407	0.460

APPENDIX B: CORRELATION MATRIX: 1930-2008

This correlation matrix shows the relationship between all of the chronologies (with different standardization techniques) developed at Hovey Lake and 86 monthly climate variables including the current year's climate and eight lagged months of discharge, precipitation, temperature, and PDSI.. Compared to the years which span 1930-1974 (Appendix A), this provides another view as to how the dam has altered the growing signal at Hovey Lake.

Red filled cells indicate variables which have met or exceeded the significance value of 0.283 (n = 80, p = 0.01, and yellow filled cells indicate variables which have met or were less than the significance value of -0.283.

PDSI: Palmer Drought Severity Index

CFS: Cubic Feet per second: a common unit of discharge

P: Precipatation for a given month.

T: Temperature for a given month

p: Prior month's reading

raw: unstandardized ring-width chronology in ARSTAN

std: standard ARSTAN chronology (based on user-entered parameters, still retains autocorrelation)

res: residual ARSTAN chronology (from which autocorrelation is removed) ars: ARSTAN chronology (autocorrelation is removed, then modeled to how the stand should act as if it were autocorrelated)

ne: negative exponential curve standardization (assumes the same amount of cells will be put on the tree each year, while the trunk width keeps increasing)

hmc: horizontal mean curve standardization (average horizontal line)

40: 40 year smoothing spline standardization (takes out half the variance after 40 years, filters extraneous noise)

	rawne	stdne	resne	arsne	rawhmc	stdhmc	reshmc	arshmc	raw40	std40	res40	ars40
MayCFSp	-0.140	-0.105	-0.140	-0.058	-0.141	-0.158	-0.171	-0.112	-0.140	-0.087	-0.147	-0.070
JuneCFSp	0.073	0.133	-0.032	0.111	0.074	0.094	-0.043	0.074	0.073	0.102	-0.021	0.084
JulyCFSp	-0.030	0.002	0.027	-0.055	-0.028	-0.007	0.015	-0.064	-0.030	-0.043	-0.003	-0.090
AugCFSp	0.167	0.186	0.181	0.178	0.164	0.165	0.149	0.147	0.167	0.111	0.119	0.087
SepCFSp	0.053	0.132	0.234	0.109	0.053	0.065	0.185	0.053	0.053	0.020	0.137	0.010
OctCFSp	-0.034	0.058	0.245	0.073	-0.034	-0.027	0.199	-0.002	-0.034	0.021	0.197	0.017
NovCFSp	-0.144	-0.109	0.053	-0.076	-0.145	-0.161	0.029	-0.101	-0.144	-0.193	-0.008	-0.171
DecCFSp	-0.173	-0.118	-0.027	-0.081	-0.173	-0.182	-0.069	-0.140	-0.173	-0.151	-0.065	-0.141
JanCFS	-0.067	-0.123	0.000	-0.163	-0.070	-0.089	0.075	-0.118	-0.067	-0.124	0.027	-0.150
FebCFS	0.005	-0.047	-0.130	-0.110	0.006	-0.009	-0.084	-0.047	0.005	-0.089	-0.100	-0.114
MarCFS	0.079	0.014	-0.079	0.023	0.078	0.061	-0.066	0.053	0.079	-0.027	-0.073	-0.032
AprCFS	0.161	0.118	0.182	0.112	0.160	0.165	0.194	0.150	0.161	0.091	0.103	0.070
MayCFS	-0.007	-0.005	-0.005	0.056	-0.007	-0.027	-0.007	0.025	-0.007	0.002	-0.021	0.009
JuneCFS	0.117	0.167	0.072	0.134	0.119	0.128	0.070	0.116	0.117	0.116	0.071	0.102
JulyCFS	-0.056	-0.031	0.072	-0.051	-0.057	-0.049	0.072	-0.047	-0.056	-0.081	0.002	-0.085
AugCFS	0.097	0.102	0.271	0.136	0.094	0.104	0.257	0.124	0.097	0.066	0.207	0.066
SepCFS	-0.072	-0.038	0.020	-0.048	-0.073	-0.061	0.010	-0.072	-0.072	-0.075	-0.022	-0.078
OctCFS	-0.188	-0.105	-0.063	-0.082	-0.187	-0.173	-0.094	-0.149	-0.188	-0.112	-0.112	-0.086
NovCFS	-0.110	-0.095	-0.065	-0.027	-0.110	-0.126	-0.072	-0.066	-0.110	-0.151	-0.151	-0.086
DecCFS	-0.094	-0.065	-0.077	-0.017	-0.093	-0.109	-0.093	-0.077	-0.094	-0.086	-0.116	-0.061
MayPp	-0.113	-0.044	-0.075	-0.072	-0.109	-0.102	-0.125	-0.116	-0.113	0.000	-0.041	-0.012
JunPp	0.061	0.119	-0.096	0.103	0.062	0.086	-0.127	0.081	0.061	0.123	-0.048	0.134
JulPp	-0.178	-0.161	-0.258	-0.083	-0.176	-0.203	-0.285	-0.151	-0.178	-0.170	-0.277	-0.102
AugPp	0.257	0.313	0.306	0.326	0.257	0.245	0.299	0.294	0.257	0.277	0.258	0.280
SepPp	-0.009	-0.012	0.018	-0.040	-0.013	-0.012	0.026	-0.036	-0.009	0.006	0.048	-0.018
OctPp	-0.117	-0.074	0.017	-0.101	-0.118	-0.095	0.020	-0.126	-0.117	-0.031	0.076	-0.041
NovPp	-0.192	-0.149	-0.050	-0.110	-0.192	-0.205	-0.069	-0.171	-0.192	-0.118	-0.097	-0.095
DecPp	-0.142	-0.100	0.093	-0.061	-0.144	-0.138	0.058	-0.119	-0.142	-0.002	0.117	0.000
JanP	0.149	0.111	0.197	0.153	0.146	0.154	0.231	0.185	0.149	0.172	0.166	0.175
FebP	-0.081	-0.065	0.074	-0.036	-0.079	-0.074	0.028	-0.089	-0.081	0.002	0.088	0.010
MarP	0.129	0.187	0.197	0.180	0.129	0.159	0.169	0.147	0.129	0.199	0.198	0.207
AprP	-0.047	0.035	0.144	0.045	-0.047	-0.016	0.109	0.008	-0.047	0.106	0.179	0.116
MayP	-0.096	0.004	0.135	-0.007	-0.098	-0.064	0.110	-0.050	-0.096	0.100	0.156	0.096
JunP	0.185	0.212	0.199	0.230	0.190	0.204	0.219	0.225	0.185	0.268	0.232	0.284
JulP	0.008	0.067	0.069	0.115	0.010	0.001	0.033	0.028	0.008	0.107	0.073	0.126
AugP	0.154	0.219	0.044	0.230	0.154	0.176	0.046	0.192	0.154	0.199	0.012	0.207
SepP	-0.054	-0.040	-0.006	-0.069	-0.057	-0.046	0.014	-0.069	-0.054	0.013	0.008	-0.002
OctP	-0.166	-0.099	-0.015	-0.131	-0.168	-0.151	-0.012	-0.159	-0.166	-0.088	-0.033	-0.075
NovP	-0.124	-0.075	0.042	-0.081	-0.122	-0.117	0.016	-0.137	-0.124	-0.019	0.053	-0.027
DecP	-0.178	-0.112	-0.018	-0.102	-0.180	-0.187	-0.042	-0.168	-0.178	-0.065	-0.013	-0.059
SumP	-0.011	0.122	0.169	0.123	-0.010	0.024	0.158	0.043	-0.011	0.222	0.180	0.234
AnnP	-0.012	0.122	0.280	0.143	-0.012	0.029	0.249	0.049	-0.012	0.259	0.292	0.273
MayTp	0.024	0.043	0.013	0.037	0.026	0.056	0.000	0.025	0.024	0.067	0.042	0.041
JunTp	-0.029	-0.124	-0.055	-0.151	-0.028	-0.037	0.017	-0.060	-0.029	-0.143	-0.065	-0.182

JulTp	0.046	-0.018	0.099	-0.061	0.042	0.065	0.145	0.031	0.046	-0.038	0.065	-0.075
AugTp	0.039	0.018	0.106	0.008	0.039	0.058	0.102	0.041	0.039	0.077	0.126	0.067
SepTp	-0.074	-0.195	-0.156	-0.166	-0.074	-0.112	-0.102	-0.091	-0.074	-0.164	-0.164	-0.163
OctTp	0.031	-0.033	0.051	-0.058	0.033	-0.001	0.078	-0.002	0.031	-0.006	0.049	-0.020
NovTp	-0.150	-0.033	0.129	-0.034	-0.150	-0.124	0.094	-0.104	-0.150	0.037	0.121	0.059
DecTp	-0.066	-0.052	0.124	-0.001	-0.065	-0.074	0.111	-0.013	-0.066	0.017	0.135	0.048
JanT	-0.152	-0.159	0.092	-0.166	-0.155	-0.134	0.132	-0.132	-0.152	-0.095	0.055	-0.103
FebT	-0.072	-0.025	0.056	-0.077	-0.075	-0.033	0.083	-0.082	-0.072	0.031	0.102	0.003
MarT	-0.008	0.063	0.007	0.011	-0.005	0.018	-0.013	-0.031	-0.008	0.079	0.057	0.055
AprT	-0.048	0.006	-0.010	-0.002	-0.048	-0.038	0.012	-0.047	-0.048	0.029	0.034	0.033
MayT	0.020	0.074	0.028	0.047	0.020	0.039	0.009	0.032	0.020	0.087	0.057	0.087
JunT	-0.076	-0.139	-0.183	-0.147	-0.079	-0.098	-0.182	-0.102	-0.076	-0.137	-0.185	-0.143
JulT	-0.094	-0.163	-0.278	-0.211	-0.097	-0.097	-0.231	-0.121	-0.094	-0.236	-0.304	-0.242
AugT	-0.007	-0.050	-0.045	-0.061	-0.007	-0.006	-0.011	-0.004	-0.007	-0.056	-0.052	-0.046
SepT	-0.001	-0.056	-0.157	-0.096	-0.007	-0.008	-0.116	-0.049	-0.001	-0.063	-0.092	-0.077
OctT	-0.050	-0.078	-0.003	-0.098	-0.049	-0.043	-0.003	-0.043	-0.050	-0.063	0.001	-0.053
NovT	-0.253	-0.156	-0.142	-0.154	-0.253	-0.218	-0.174	-0.211	-0.253	-0.152	-0.124	-0.151
DecT	-0.141	-0.157	-0.136	-0.126	-0.145	-0.181	-0.142	-0.133	-0.141	-0.153	-0.161	-0.137
SumT	-0.058	-0.114	-0.179	-0.163	-0.062	-0.057	-0.150	-0.080	-0.058	-0.126	-0.153	-0.128
AnnT	-0.226	-0.195	-0.123	-0.249	-0.231	-0.201	-0.094	-0.229	-0.226	-0.149	-0.087	-0.163
MayPDSIp	-0.107	-0.015	-0.169	-0.019	-0.103	-0.107	-0.259	-0.111	-0.107	0.022	-0.118	0.023
JunPDSIp	-0.028	0.087	-0.131	0.105	-0.025	-0.018	-0.224	-0.008	-0.028	0.133	-0.064	0.150
JulPDSIp	-0.109	-0.026	-0.248	0.033	-0.106	-0.124	-0.337	-0.089	-0.109	-0.004	-0.216	0.042
AugPDSIp	-0.007	0.074	-0.115	0.124	-0.006	-0.032	-0.177	0.021	-0.007	0.079	-0.103	0.121
SepPDSIp	-0.010	0.069	-0.071	0.101	-0.011	-0.029	-0.126	0.006	-0.010	0.076	-0.048	0.105
OctPDSIp	-0.039	0.041	-0.039	0.069	-0.039	-0.043	-0.081	-0.023	-0.039	0.061	-0.011	0.084
NovPDSIp	-0.079	0.002	-0.032	0.039	-0.079	-0.085	-0.073	-0.055	-0.079	0.029	-0.021	0.055
DecPDSIp	-0.072	0.024	0.038	0.066	-0.073	-0.069	-0.008	-0.038	-0.072	0.088	0.064	0.097
JanPDSI	-0.063	0.020	0.094	0.068	-0.064	-0.049	0.053	-0.012	-0.063	0.118	0.104	0.135
FebPDSI	-0.041	0.038	0.141	0.074	-0.041	-0.032	0.089	-0.013	-0.041	0.126	0.151	0.145
MarPDSI	0.047	0.137	0.246	0.156	0.047	0.078	0.202	0.086	0.047	0.203	0.236	0.213
AprPDSI	0.037	0.145	0.293	0.163	0.038	0.071	0.244	0.087	0.037	0.240	0.301	0.253
MayPDSI	0.014	0.149	0.312	0.170	0.014	0.054	0.258	0.082	0.014	0.264	0.332	0.275
JunPDSI	0.117	0.247	0.335	0.278	0.120	0.155	0.290	0.178	0.117	0.355	0.368	0.369
JulPDSI	0.119	0.253	0.332	0.293	0.123	0.147	0.276	0.169	0.119	0.357	0.369	0.372
AugPDSI	0.152	0.270	0.269	0.306	0.153	0.175	0.237	0.202	0.152	0.329	0.278	0.342
SepPDSI	0.103	0.215	0.235	0.243	0.104	0.127	0.207	0.145	0.103	0.284	0.237	0.295
OctPDSI	0.027	0.154	0.183	0.154	0.028	0.058	0.154	0.057	0.027	0.212	0.178	0.220
NovPDSI	-0.011	0.113	0.171	0.115	-0.010	0.019	0.143	0.018	-0.011	0.182	0.172	0.189
DecPDSI	-0.052	0.106	0.175	0.094	-0.051	-0.008	0.143	-0.016	-0.052	0.176	0.190	0.184
SumPDSI	0.101	0.244	0.315	0.273	0.102	0.135	0.269	0.158	0.101	0.341	0.334	0.355
AnnPDSI	0.044	0.189	0.286	0.217	0.045	0.079	0.235	0.099	0.044	0.293	0.299	0.308