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Drought Sensitivity of Slash Pine and Longleaf Pine Deduced by Tree Ring Analysis

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Abstract

Annual tree rings give us the opportunity to investigate the adaptation of trees to climate and environmental changes over a long period of time. In particular, the physical characteristics of each ring (width and earlywood and late wood differentiation) can be used to reconstruct past environment conditions. Physiological responses of trees will be evaluated for two conifers species, i.e. Longleaf pine and Slash pine, giving the opportunity to compare the two species and understand how each species (Longleaf pine and Slash pine) adapt their water use to thrive in such extreme environments. Growth data will then be related to the intrinsic Water Use Efficiency ($_i$WUE, i.e., ratio of carbon assimilated relative to stomatal conductance), derived by stable carbon isotope composition ($\delta^{13}C$) in tree rings, as one of the main tasks included in a NASA-funded project aiming to assess changes in at eleven forested Ameriflux sites across North America spanning a wide range of forest types and climate conditions.

Background

Forest health and productivity depends greatly on the amount of available water, which is constantly changing due to changes in climate. It is already well established that relationships of tree growth to climatic variation vary due to differences among species (Villalba et al. 1994). These variations among trees are present and most clear in their annual tree ring widths. These variations are apparent in periods of stress when growth rings allocate less carbon to wood, resulting in narrower rings (especially in latewood) (Meldahl et al. 1999). The variations in tree ring width as a result of climatic variables provide information on photosynthesis and response to drought, which affects the production and allocation of carbohydrates to secondary growth (stem growth).

In this study we will examine the influences of changes in precipitation and temperature (amount and intensity) on two different tree species (Pinus palustris Mill. and Pinus elliottii Engelm) using tree rings as reliable indicators. The study site is the Austin Cary Memorial Forest in Florida. Pine forests are the most widespread ecosystem types in this region of which, Pinus palustris (Longleaf pine) is largely dominant (Powell 2008). Longleaf pine is found in a large range, across the breadth of the Coastal Plain from Virginia to East Texas (Henderson Grissino-Mayer 2009). As a comparison to the dominant tree species, Pinus elliottii (Slash pine) will also be examined. Slash Pine inhabits in southern US and is the southernmost native pine in the United States (Little and Dorman 1954).

The objective of this study is to investigate how the two different pine species respond to water limitation. Stress years will be established by the dendrochronology and then analyzed against different climatic variables, including precipitation and a drought index. Their responses will also show how the stress affects the carbon investment in secondary growth. The carbon isotope ratio in plant material has been successfully used to explore the drought response and water use efficiency (WUE) of C3 plants (Farquhar and Richards 1984; Ehleringer et al. 1993). Tree growth will therefore be evaluated in relation to the d13C-derived iWUE for the two pine species and explore how drought affect the relationship between the two physiological parameters (Peñuelas et al. 2008). Due to the low water availability less carbon is assimilated, which directly affects the iWUE (the WUE is discussed further in-depth under Discussion).

Methodology

The site for this study has an overstory composed of the two pines being analyzed, Longleaf Pine and Slash Pine (72% and 28% of tree basal area), (Powell 2008). The trees height had an average of 22 meters and the soils were poorly drained, dry and sandy. Ideally this site presents a large amount of occurrences of extreme drought for this study, however as Figure 1 shows, the Palmer Drought Severity Index only goes beyond the absolute value of 3 (extreme drought) a total of three times in the past 50 years.

The wood cores from each of the two tree species were collected during summer of 2013. In particular, n=10 trees per species were randomly selected and from each tree 4 wood cores were sampled. All wood cores were dated and cross-dated, but only one was kept for dendrochronology, while the other 3 were be used for stable carbon and oxygen measurements. Furthermore, in order to build a more statistically strong ring width chronology (i.e., master chronology), an additional 5 trees were selected for collecting 1 wood core for dendromeasurements. The cores were air-dried and polished using finer and finer sandpaper from 250 grit to 1000 grit (250,320,400,600,1000). By polishing them, the growth rings become significantly more visible and easier to read and date as seen below as Figure 2. All the wood cores were dated, from the bark to the pith from 2013 to 1960. Once cores were completely dated, the annual ring widths were measured under a microscope.

Ring widths obtained from the 4 wood cores per tree and for all the trees were then cross-dated first visually and then using COFECHA software (Grissino-Mayer 2001). Cross-dating cores is a method used in dendrochronology in which each core is dated and then its width is compared to each other within a tree to result in the highest tree growth ring correlation. Ring widths will be measured using a tree analysis system (Velmex Unislide Bloomfield, NY) attached to a digital scanner (Epson Expression, 10000 XL). A visual comparison is done before the statistics test (COFECHA) because it will quickly show apparent mistakes. Converting the data to an excel file using the YUX program, gives the ability to graph each ring width time series. All the tree cores together with their measurements are shown in Figure 3 and 4. On the graph stress events will be shown by dips in the graph and flourishing years will be the peaks in the graph (largest growth rings). Studying these stress periods and after, will help us understand how each tree and tree species responds to such stressors. To further study these periods, measurements are ran through the statistical program COFECHA to ensure the cross dating is correct (Grissino-Mayer 2001). If the correlation among cores in a tree is high enough, then the trees are correlated to its same species trees within the forest. The chronology in this study was completed if all the cores are correlated with each other at a correlation higher than .6. Figure 5 and 6 show the COFECHA results for the Longleaf Pine and Slash Pine.

Once the COFECHA results are gathered, the next process is standardizing the data. The data from COFECHA is the raw tree ring width, however there is an age factor involved in that data, which needs to be removed to statistically to test the climatic effect. A 15-year spline curve is fit to the raw tree ring data to remove this growth factor, and then some autocorrelation is put back into the data since it represents climatic factors. This process is all done using the program ARSTAN, which we use the ARSTAN output as the standardized data to run against our climatic variables, as seen in Figure 7. Our climatic variables include PDSI (Palmer Drought Severity Index), precipitation, and temperature. The statistical analysis was performed using JMP. Multivariate correlations were done and the pairwise correlations were analyzed for significance.

Results

Raw Ring Width

Figure 2 shows the plot of all trees within each species and their respective core measurements. The black line throughout the figure shows the mean ring width for the whole species. Apparent in both species are dips in similar years, such as in 1963, 1987, 2000 and 2007. Figure 1 shows the sites drought history, in which 2000 and 2007 experienced extreme drought. This aligns with our raw ring data for both those years, as the ring width significantly decreases throughout the site.

COFECHA and ARSTAN

After measuring fifteen tree cores, COFECHA gave a correlation of .623 for the Longleaf Pine and .657 for the Slash Pine (Figure 6 and 7). Arstan put out an output shown in Table 2, which shows the Arstan values that were used in statistical analysis, and also the residual values in which no autocorrelation was integrated into the values. Both these outputs used a 15-year spline during the standardization process.

JMP

The initial statistical analysis is shown in Figure 8, which shows the pairwise correlation between the Arstan standardized values and climatic variables including, annual and summer precipitation, and annual and summer temperature. The annual and temperature was more correlated with growth with a .3317 (Longleaf Pine) and .2487 (Slash Pine) Pearson correlation (R), while annual precipitation had a correlation of .0342 and .1245 respectively. Temperature was then taken a step further and was separated by growing season months (May, June, July, August, September). These were then correlated (Pearson) along with the Arstan values and no significant results were calculated in either of the two pine species, however half of the values were negatively correlated (Figure 9). Precipitation was also ran through JMP with just the growing season months (Figure 10), and yielded the same result as temperature with no significant values. The precipitation correlations were however, on average higher than temperature's correlation. To supplement the precipitation analysis, the PDSI (growing season months) values were also ran through JMP using pairwise correlations with the Arstan values (Figure 11). This also yielded no significant results, however correlations were on average .4121 which is the highest average correlations of all variables.

Discussion

This study constructed longleaf pine and slash pine chronologies to determine climatic variables that each chronology has a response, and also to determine differences among the responses of the two species. Longleaf Pine was the more dominant species in the stand, however from Figure 3 it is clear that the Slash Pine grows at a higher growth rate. The raw data shows the actual mean growth of the species cores, and while the two species are significantly correlated the slash pine has been outgrowing the longleaf pine since 1960. Besides the different growth rates, the similarities are also apparent, as each species dips and peaks in the same years. These dips in the chronologies are related to the limited water availability that Figure 1 shows record of. Extreme drought occurred in 2000 and 2007, which were also dip years throughout both chronologies. This is the reasoning in choosing to analyze the precipitation and temperature of this site, to see their influences on chronology since drought seems to have an evident effect.

Temperature

Neither Longleaf Pine or Slash Pine had any significant correlation with growing season temperature (Figure 8). Correlations for both species were near negative, or were negative values. Although these results provided no significance, a similar result was found in other studies as well. Longleaf Pine has consistently had a negative correlation between warm summer temperatures (Meldahl et al., 1999; Foster and Brooks, 2001). Slash Pine also has previously shown negative correlations between tree growth and late summer temperatures (Harley 2011). The most common theory behind this negative correlation is that the high temperatures increase evapotranspiration, which results in larger respiration rates over net carbon assimilation rates (Harley 2011, Henderson Grissino-Mayer 2009).

Precipitation

Precipitation yielded higher correlations than temperature had on either tree species throughout the growing season. This indicates that both the Longleaf Pine and

Slash Pine are primarily influenced by water availability during the growing season, as opposed to being primarily influenced by temperatures. Other studies have shown similar results, however with more significance. The well researched Longleaf Pine has been identified with having significant correlations of radial growth with precipitation and drought between March and October of the current year in the Eastern Gulf and Southern Coastal Plains (Henderson 2009), and also in numerous other southern sites (Devall et al. 1991; Meldahl et al. 1999; Foster and Brooks 2001). Although Slash Pine is less documented, findings of response-function and correlation analysis revealed significant relationships between radial growth and precipitation in multiple studies. (Harley 2011, Ford and Brook 2003). These well corroborated results and the similar results from this study indicate that throughout Florida a main factor of tree growth is the water availability.

PDSI

This variable was hypothesized to have a large impact on tree growth. As Figure 10 shows, the correlations were not significant, however they were the highest of all variables. In this study only the growing season PDSI was analyzed to compare with the other variables. Other however did find significant PDSI in winter months (Bhuta 2009). PDSI, just like our arstan values, have a large degree of autocorrelation, which could explain part of this high correlation, however from this study's results compiled with others we are confident in these correlations demonstrating a meaningful relationship with growth. This higher correlation than temperature and precipitation has also been seen with other studies, which resulted in the strongest relationship between growth and PDSI to be during the growing season (Henderson Grissino-Mayer 2009, Meldahl et al. 1993). With this being our highest correlations, it is clear that water availability limits growth at this sites. The lack of significance may lead to the fact that at this stand, there has not been a sufficient amount of extreme drought. While this is a fairly dry site, only 3 extreme droughts have occurred since 1960, and this may not be enough to show an effect on our data. Other studies have found that the PDSI datapoint is not near to their site (Harley 2011), yet for this study the datapoint was close, only drought was too infrequent.

Conclusion

This study determined that the Longleaf Pine and Slash Pine are both strongly influenced by growing season temperature, precipitation and PDSI. Both species are influenced the most by PDSI, and respond to drought by limiting its radial growth's. While Slash Pine had a larger growth factor curve, when standardized both species responded similarly to the climatic variables. This response to drought should be considered in future management plans that incorporate the growth of longleaf pine or slash pine in Florida. Extreme drought in this area, along with higher mean temperature and mean precipitation will increase as climate change takes it effect throughout North America. Both these pines dominate in high drought and fire areas making these management plans more complicated.

A larger database of PDSI, temperature and precipitation would have benefited this study and potentially resulted in significant results. This research showcases the variability of the relationship between these two species radial growth and climatic factors, however more climatic factors (VPD) need to be studied to fully understand the relationship. Research that fills the gap of spatial variations and enhancing prediction of future distributions under changing climate would contribute to a better understanding of the ecology of these two species as well.

Works Cited

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Figure 1: The past history of drought in Austin Cary Memorial Forest, FL.

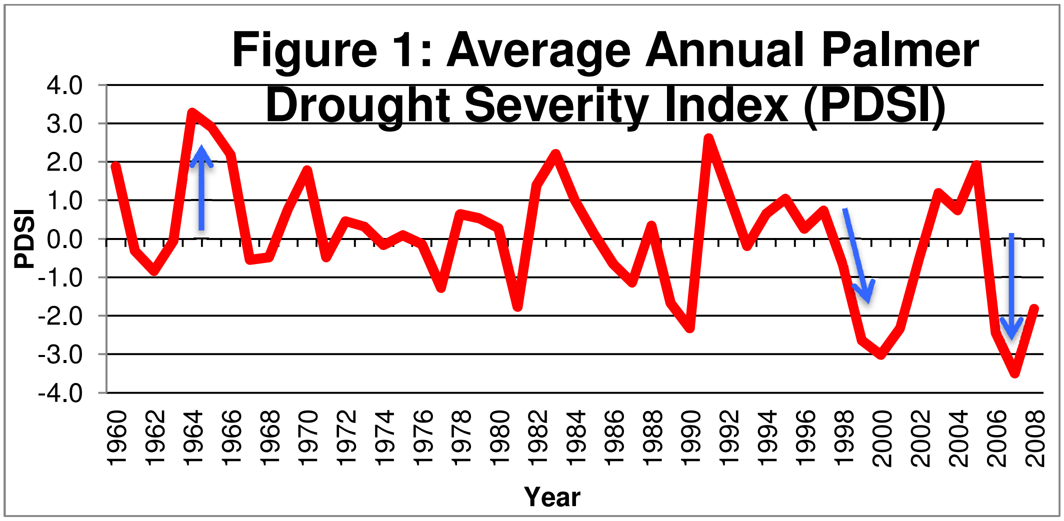

Figure 2: Cores before and after cleaning

Core before cleaning *Core after cleaning*

Figure 2: The core on the left was not cleaned with a razor, while the core on the left was cleaned for easier reading.

Figure 3: PIPA Growth Pattern

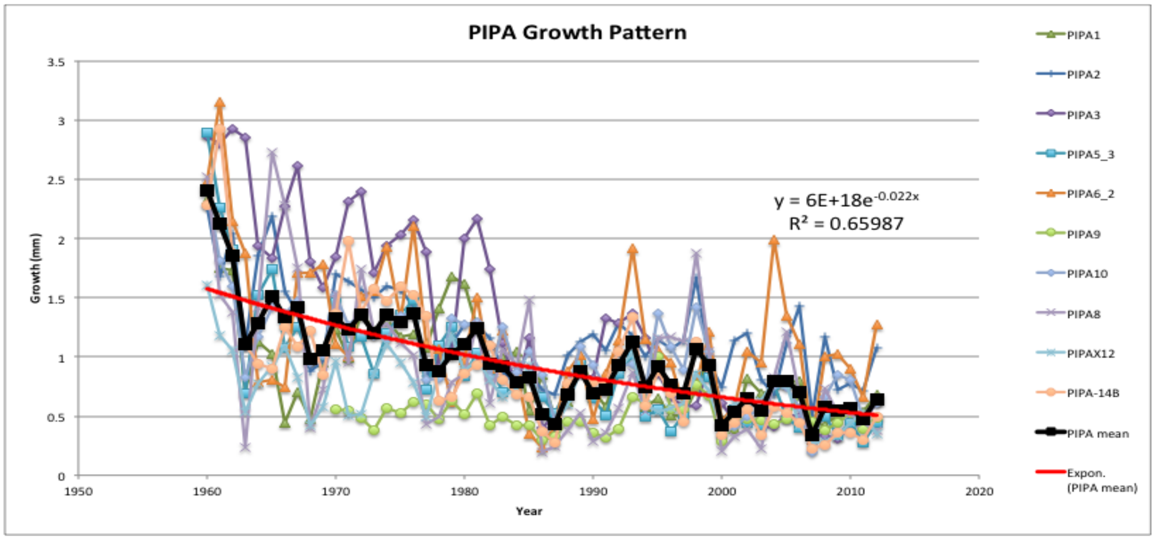

Figure 3: Longleaf Pine core's raw ring widths with the mean ring width bolded, along with the negative exponential line fit to reduce the growth rate.

Figure 4: PIEL Growth Pattern

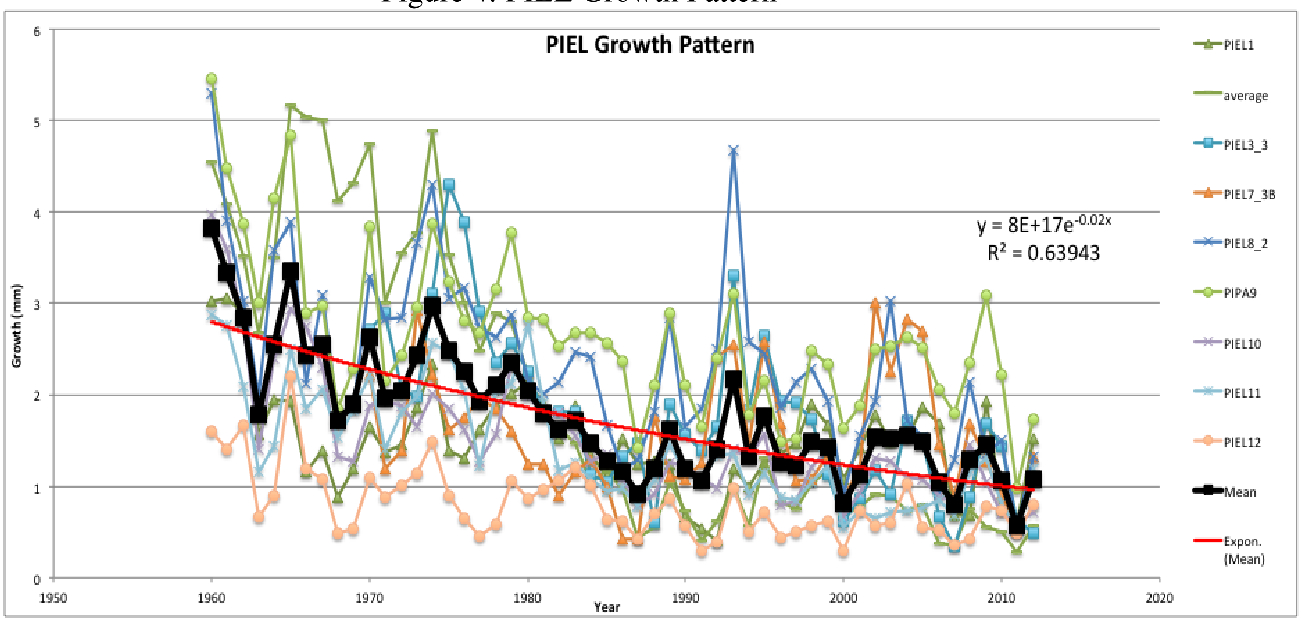

Figure 4: Slash Pine's core's raw ring widths with the mean ring width bolded, along with the negative exponential line fit to reduce the growth rate.

Figure 5: PIPA COFECHA Results

Seq	Series	Interval	No. Years	No. Segmt	No. Flags	Corr with Master
1	PIPA1_2	1960 2012	53	4	0	.523
2	PIPA1_3	1960 2013	54	4	0	.544
3	PIPA2_1	1960 2012	53	4	0	.752
4	PIPA2_3	1960 2012	53	4	0	.650
5	PIPA2_4	1960 2012	53	4	0	.728
6	PIPA3_1	1970 2012	43	3	1	.465
7	PIPA3_4	1960 2012	53	4	3	.329
8	PIPA5_3	1960 2012	53	4	0	.660
9	PIPA6_2	1960 2012	53	4	2	.480
10	PIPA8_4	1960 2012	53	4	0	.590
11	PIPA9_1	1960 2012	53	4	1	.412
12	PIPA10_2	1960 2012	53	4	0	.765
13	PIPA10_3	1960 2012	53	4	0	.719
14	PIPA10_4	1960 2012	53	4	0	.770
Total or mean:			733	55	7	.601

Figure 5: COFECHA final results for Longleaf Pine, with a master correlation of .601

Figure 6: PIEL COFECHA Results

Seq	Series	Interval	No. Years	No. Segmt	No. Flags	Corr with Master
1	PIEL1_2B	1960 2012	53	4	2	.518
2	PIEL1_3	1960 2012	53	4	0	.682
3	PIEL1_4	1960 2012	53	4	0	.541
4	PIEL2_2	1970 2012	43	3	0	.801
5	PIEL2_3	1960 2012	53	4	0	.597
6	PIEL2_4	1965 2012	48	3	0	.689
7	PIEL3_3	1970 2012	43	3	1	.366
8	PIEL7_3B	1970 2012	43	3	0	.543
9	PIEL8_2	1960 2012	53	4	0	.714
10	PIEL9_1F	1960 2012	53	4	1	.564
11	PIEL9_2F	1960 2012	53	4	0	.795
12	PIEL9_4F	1960 2012	53	4	0	.768
13	PIEL10_1	1960 2012	53	4	0	.639
14	PIEL10_3	1960 2012	53	4	0	.775
15	PIEL10_4	1960 2012	53	4	0	.699
16	PIEL11	1960 2012	53	4	0	.710
17	PIEL12	1960 2012	53	4	0	.717
Total or mean:			866	64	4	.657

Figure 6: COFECHA final results for Slash Pine, with a master correlation of .657

Figure 7: Arstan Standardized Values

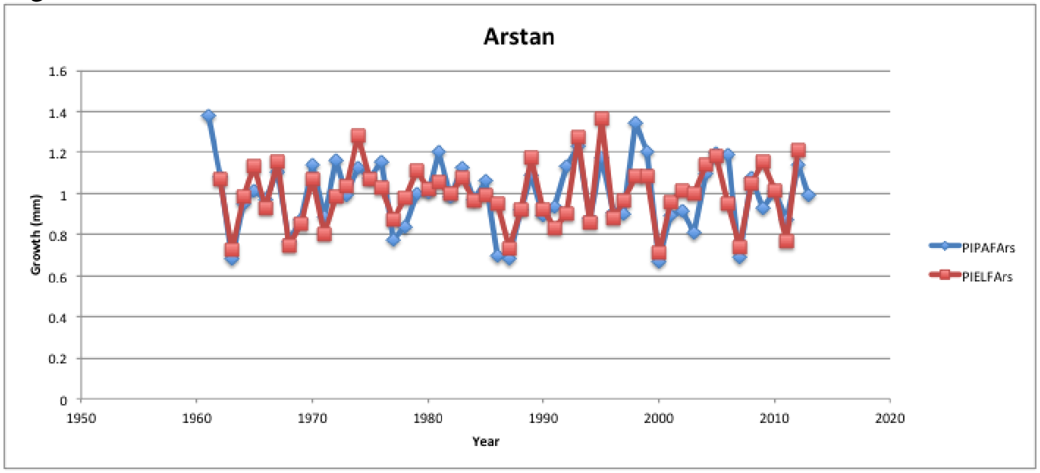

Figure 7: Standardized values of both species, with autocorrelation added back into the values.

Figure 8: Initial JMP Pairwise Correlations

Variable	by Variable	Correlation	Signif Prob
PIEL	PIPA	0.716	<.0001
PDSI	PIPA	0.1122	0.4478
PDSI	PIEL	0.1952	0.1836
annual precip	PIPA	0.0342	0.871
annual precip	PIEL	0.1245	0.5533
annual temp	PIPA	0.3317	0.1052
annual temp	PIEL	0.2487	0.2306
summer precip	PIPA	0.0172	0.9351
summer precip	PIEL	0.1393	0.5067
summer temp	PIPA	0.3317	0.1052
summer temp	PIEL	0.2487	0.2306

Figure 8: Growing season correlated the best among all variables

Figure 9: Monthly Temperature Pairwise Correlations with Arstan Values

Variable	by Variable	Correlation	Count	Lower 95%	Upper 95%	Signif Prob	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
PIPA Residual	May	0.1016	39	-0.2210	0.4042	0.5383	
PIPA Residual	June	0.0855	39	-0.2364	0.3905	0.6049	
PIPA Residual	July	0.3507	39	0.0396	0.5998	0.0286*	
PIPA Residual	August	0.0703	39	-0.2508	0.3775	0.6706	
PIPA Residual	September	0.2113	39	-0.1117	0.4939	0.1967	
PIEL Residual	May	-0.0451	38	-0.3596	0.2786	0.7881	
PIEL Residual	June	-0.1018	38	-0.4082	0.2252	0.5429	
PIEL Residual	July	0.1101	38	-0.2172	0.4152	0.5104	
PIEL Residual	August	-0.0700	38	-0.3812	0.2554	0.6760	
PIEL Residual	September	0.2131	38	-0.1144	0.4988	0.1990	
PIEL Residual	CO2 annual	0.1643	38	-0.1640	0.4598	0.3244	
PIPA Residual	CO2 annual	0.1823	39	-0.1414	0.4707	0.2667	

Figure 9: Correlations had no significance and average correlation is .13.

Figure 10: Monthly Precipitation Pairwise Correlations with Arstan Values

Variable	by Variable	Correlation	Count	Lower 95%	Upper 95%	Signif Prob	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
PIPA Ars	May	-0.0934	39	-0.3972	0.2288	0.5716	
PIPA Ars	June	0.1719	39	-0.1518	0.4624	0.2953	
PIPA Ars	July	-0.2078	39	-0.4911	0.1153	0.2043	
PIPA Ars	August	0.1424	39	-0.1812	0.4382	0.3871	
PIPA Ars	September	-0.1136	39	-0.4143	0.2094	0.4911	
PIEL Ars	May	-0.0923	38	-0.4002	0.2343	0.5814	
PIEL Ars	June	0.2034	38	-0.1243	0.4912	0.2205	
PIEL Ars	July	-0.1231	38	-0.4260	0.2047	0.4617	
PIEL Ars	August	0.2515	38	-0.0741	0.5287	0.1277	
PIEL Ars	September	0.0436	38	-0.2800	0.3583	0.7948	

Figure 10: Correlations had no significance and the average correlation across species is .144.

Figure 11: Monthly PDSI Pairwise Correlations with Arstan Values

Variable	by Variable	Correlation	Count	Lower 95%	Upper 95%	Signif Prob	-.8 -.6 -.4 -.2 0 .2 .4 .6 .8
PIPA Arstan	May	0.1659	48	-0.1241	0.4298	0.2597	
PIPA Arstan	June	0.1569	48	-0.1332	0.4222	0.2868	
PIPA Arstan	July	0.0637	48	-0.2245	0.3417	0.6670	
PIPA Arstan	August	0.0571	48	-0.2307	0.3358	0.6997	
PIPA Arstan	September	0.0785	48	-0.2103	0.3547	0.5959	
PIEL Arstan	May	0.1972	47	-0.0954	0.4584	0.1840	
PIEL Arstan	June	0.2222	47	-0.0694	0.4788	0.1334	
PIEL Arstan	July	0.1550	47	-0.1383	0.4233	0.2982	
PIEL Arstan	August	0.1671	47	-0.1261	0.4334	0.2617	
PIEL Arstan	September	0.1783	47	-0.1148	0.4428	0.2306	

Figure 11: Correlations had no significance, but the average correlation was the highest variable correlation across species at .15.