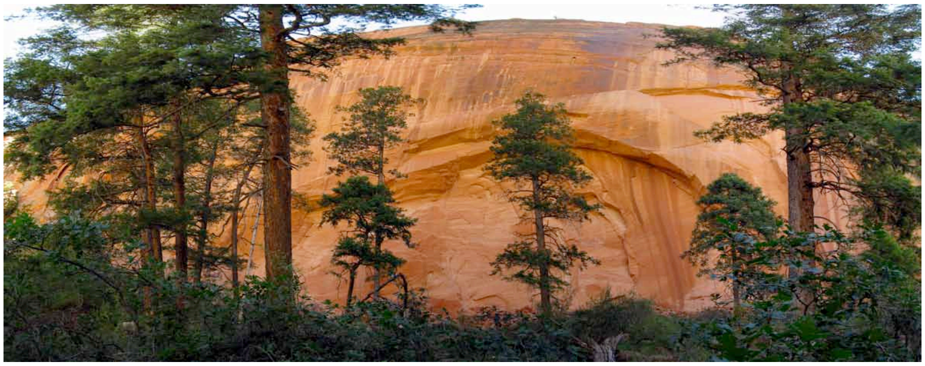
A PINHEAD INTERNSHIP

Victor Major -August 2009



Douglas-fir and Navajo sandstone at the Tsegi Canyon tree-ring site in northern Arizona

For six weeks in the summer of 2009, I participated in the Pinhead Institute's Science Internship program as an assistant at the University of Arizona Laboratory of Tree-Ring Research. My involvement was focused around dendrochronology. Dendrochronology is a method that uses information found in precisely dated tree rings to address a variety of concepts and questions. A subset of dendrochronology is dendroclimatology. Dendroclimatic reconstructions use basic tree-ring methodology to help extend instrumental climate records and study climate variability and change. Our project is using dendroclimatology to investigate the North American Monsoon and its precipitation variability in the American Southwest. As an intern on this project, I assisted in the field and the lab with sample collection and processing. In order to augment my experience, I was assigned a series of topical readings and the task of writing this document, which overviews tree-ring dating, climate reconstruction, our monsoon project, and my internship experience.

I. Dendrochronology

The use of tree's annual growth rings to answer and date various scientific queries is known as dendrochronology. However, the practice of dendrochronology goes much, much further than simple dating. Tree-ring dating can be applied ecology, where it conveys information of the dynamics of the forest and fires within that forest. Another function of dendochronology is the dating of archeological sites. For example, you can use wood from an ancient building to assign an exact calendar year to when timbers for that specific building were cut. In dendroclimatology, tree-rings serve as a precisely dated proxy for the past climate and events such as drought or heavy frost cycles in the spring. Furthermore, tree-ring dating is simple and therefore easily harnessed for educational or conservational purposes.

The basis and primary concept for dendrochronology is cross-dating (Douglass 1941). Cross-dating is the matching of patterns in the rings of a tree and the assignment of exact calendar years to each specific ring. For cross-dating to be accurate and verifiable, it is necessary for several conditions to be present (Stokes and Smiley 1996). The first condition is that for each year the tree only adds one ring of growth. Secondly, there must be one primary environmental factor limiting the growth of the tree. For example, in the American Southwest, the limiting factor is soil moisture, which is modulated by precipitation. Third, the limiting factor must vary from year to year resulting in respective variations within the tree rings. These patterns of variation in tree-ring widths make cross-dating applicable (Douglass 1941). And, in order for composite chronologies to be created, the limiting factor must be in effect over a large geographical area.

Also, important to the variation in tree-ring width is site selection (Stokes and Smiley 1996). If trees have access to water on a constant basis, their rings will show little or no variation in accordance with the climate. These rings are known as complacent. A choice site (Figure 1) is one with limited access to water and where other factors such as soil and light are relatively constant between trees. Often the sites with the most sensitivity are steep, rocky slopes where the species of interest is in the outer limits of its geographical range.

Figure 1. Moisture-stressed Douglas-fir trees growing on a sparsely vegetated hillslope inWhite Canyon, Utah. This site is well-suited to sampling trees for climate reconstruction.

Furthermore, at a site, in order to create detailed and lengthy chronologies from trees rings, it is necessary to sample a spectrum of young, and old trees, and if possible, remnant wood. The young trees will aid in cross-dating, while the oldest wood will lengthen the chronology. The oldest trees are physically characterized primarily by, among others, a spiked top, a lateral twist in the trunk, and few gnarled branches (Schulman 1954). If remnant wood is collected and dated with the chronology, it can extend the chronology back hundreds and in some cases thousands of years.

Once a site has been selected, sample collection begins. Cores are collected with the use of an increment borer (Figure 2) and cross-sections are collected with a saw of some type. A core

Figure 2. A core being removed from a tree in a non-destructive way using an increment borer and spoon.

is small narrow cylinder shaped somewhat like a pencil. A cross-section of wood is a section a couple of inches thick that includes the entire radial, or horizontal surface. After collection, the cores are processed in the lab. The first step is to inventory all of the cores. Once they have all been inventoried, the cores are mounted on small wood platforms using a combination of glue and tape. Data from each core is recorded at and on each step. Next, the cores are prepared for microscope work in the wood shop where they are cut and sanded down very finely until the surface becomes polished and smooth.

Under the microscope, the first step is to cross-date the cores. Cross-dating is the recognition of the same ring pattern in different trees, so that the actual growth date of ring may be assigned and carried across to other rings in different trees with the same pattern (Douglass 1941). Depending on the season in which the sample was taken and whether there have been any external effects on the core (i.e. fire, mortality) the outermost ring indicates the present last active growing season. With the knowledge of the outermost date and patterns in other rings, the dendrochronologist can assign years to individual rings. This practice of dating becomes much easier and more reliable with the scientist's familiarity of that particular site's chronology. For instance, if the one knows that 1939 is generally a small ring and 1940 is relatively much larger. And he finds that he has tentatively assigned 1939 to a large ring just before a small one, the dendrochronologist will know that the dates he has assigned from his last solid pattern are off by one year. Then, he must go back and test another date and see if that year fits better with the chronology. This methodology, developed by A.E. Douglas in the early 20th century at the University of Arizona, ensures the precision and accuracy of dendrochronology.

Every decade, half-century, century, and millennia are transcribed on the core using dots. Dots are also used to demark where missing or mirco rings are found. A diagonal slash across a ring means that it is not actually a ring, but a false one. These marks aid in keeping each ring and the corresponding measurements aligned with the correct year. Once cross-dated, the cores are measured using a low-power binocular dissecting microscope and a moving platform that measures to the nearest micron, or thousandth of a millimeter. The platform is connected to a computer that tracks and records all of the measurements (Figure 3). The boundaries of a ring are measured and defined from the beginning of the earlywood to the end of the latewood, (Figure 4).

Figure 3. Me using a stage micrometer, a microscope, and the Matlab system to measure intra-annual ring widths.

Next, all of the measurements from one site are averaged together into a site chronology that reduces noise of the data and can used with statistical analysis. When the chronology measurements are made correctly, the ratios of the ring widths can correlate very highly with climate, specifically drought or wet years. Furthermore, these correlations can be used to infer information about the full natural variability of the past climate, which will likely underlie changes in the future climate.

What allows dendrochronology to be so accurate and effective is the basic wood anatomy. In conifers, wood is formed primarily of capillary-like cells known as tracheids. These trachieds run vertically up the tree transport water and nutrients absorbed by the root system in the ground. When the samples are prepared correctly, it is possible to see individual trachieds (Figure 4). The earlywood is made up of large, open vessels for transporting plentiful resources up the tree because the early wood is developed in the spring when resources are abundant. The latewood consists of smaller, tighter cells that are pressed closer together; the latewood appears darker because the secondary cell walls are thicker and more dense. The latewood is developed later in the primary growing season (i.e. summer). The ring boundary is clearly defined by the sharp termination of latewood cells.

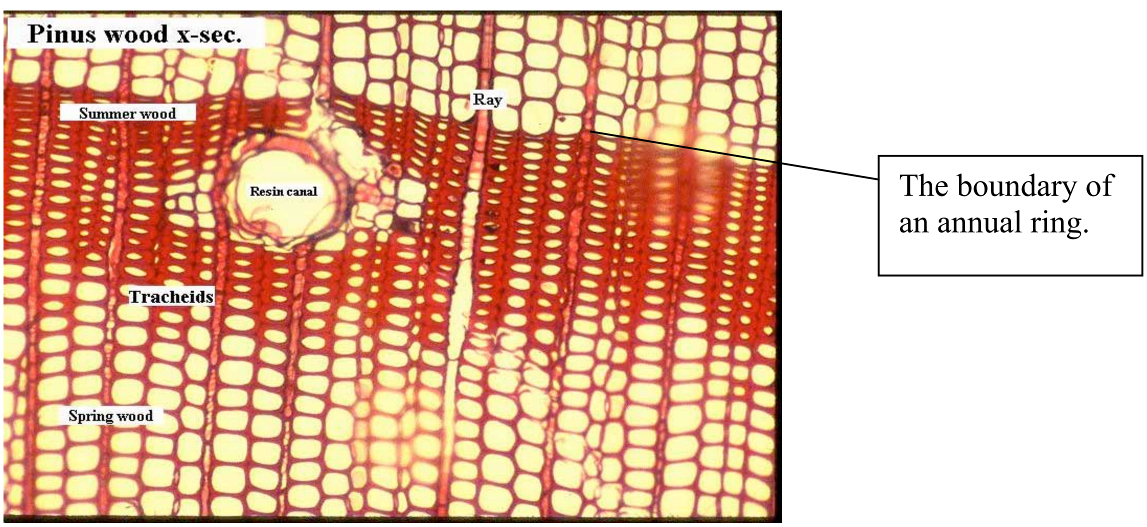


Figure 4. This is a close up photo of a tree-ring. You can cleary see the early wood in the upper and lower thirds of the photo and the latewood in the middle third. The ring boundary is clearly defined by the latewood. (R. Geeta, August 2003. Plant Diversity. http://life.bio.sunysb.edu/ee/geeta/Plant_Diversity.html.)

II. Dendroclimatology

In this time of increasing pressure and demand on water resources, it is very important for us to understand and effectively plan for extreme hydrologic variations, such as sustained drought (Woodhouse 2001). Our current knowledge of climatic variation is limited by the brevity of instrumental records. This record of can be extended much further back in time with tree-ring data. Using basic the methods of dendrochronology and simple statistical regression, it is possible to use tree growth as a proxy for precipitation and streamflow, reconstructing the history of drought and wetness across space and through time. In recent years, water managers have begun using tree-ring reconstructions of streamflow for the purposes of drought planning (http://www.treeflow.info).

Tree-ring width is a representative proxy for streamflow because the primary factors that limit tree-growth are also the primary factors that influence streamflow, particularly precipitation and evapotranspiration (Meko and Graybill 1995) (Figure 5). Depending on the site selection, tree-ring variation can reflect fluctuations in several different variables. Most sites in the American Southwest are chosen for their sensitivity to moisture stress. In the U.S. Southwest most tree's primary growth is provided by recharged soil moisture from cool season precipitation, the primary contributor to spring runoff in rivers. This cool season precipitation is controlled by regional and continental climate patterns and therefore, there is a broad geographical area in which the trees can be representative of streamflow. For this reason, tree-ring chronologies are often used from dry, south and west facing hillsides well above the river or even outside of the drainage basin. This physical relationship is evident in a strong correlation between tree-ring width and annual streamflow data. Additionally, tree-ring reconstructions closely track inter-annual moisture variability, including both drought and wetness. In some cases, tree-ring chronologies are better representative of drought because their growth is limited largely by water access. When conditions are exceptionally moist and trees have plenty of available moisture, their growth may become limited by other factors. Across the western U.S., climate and hydrologic records have been extended back in time hundreds, and in some cases thousands of years with dendrohydrologic reconstructions.

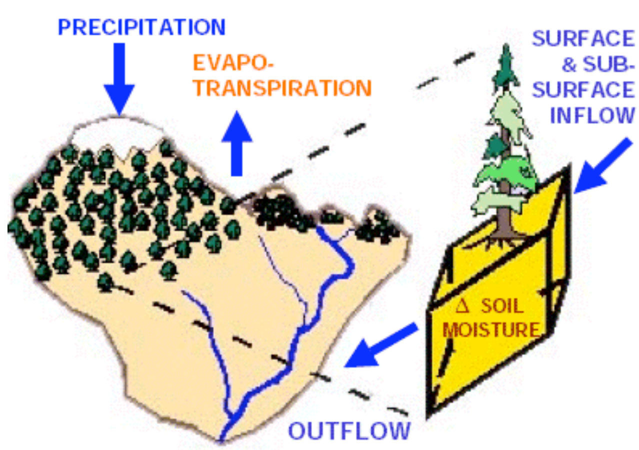


Figure 5. The soil moisture around a tree is reflective of the soil moisture in that geographical area. Therefore the tree is also representative of precipitation and streamflow in that geographical area. (Diagram courtesy of D. Meko).

Dendrohydrologic reconstructions are created by statistically regressing tree-ring chronologies on an instrumental time series and using tree-rings as the predictor to model the instrumental series (e.g., Fritts 1976, Cleaveland 2000, Meko et. al 2001). When reconstructing streamflow, the typical instrumental record used is from a river gauge. In most rivers in the western U.S., the flow has been disturbed, therefore, natural flow estimates are used in most cases to account for manmade diversions. Often using multiple linear or principle components regression, chronologies are calibrated with the instrumental record and verified against independent flow data withheld from the model. The accuracy of the regression and independent verification is reported most often by the explained variance or squared correlation (R^2), 50 to 70% being a "good" statistic (Woodhouse and Meko 2007). The regression model is then applied to the full length of the tree-ring chronology. The resulting tree-ring reconstruction functions as an accurate and lengthy extension of the instrumental record of hydrologic variation (Figure 6).

Several watersheds have been studied using tree-ring data and statistical methods to infer information of the past river flow. In 2001, Connie Woodhouse published a paper on the hydrologic reconstruction of the Middle Boulder Creek focusing on the water resources of the Colorado Front Range. Woodhouse used four chronologies from the Middle Boulder Creek drainage area and multiple linear regression to estimate streamflow back to 1703. She concluded that the worst drought of the three-hundred year reconstruction was in the 1840’s and 50’s and if a drought similar to that were to happen today, it would threaten the Front Range’s water supply, especially if population growth in that area continues at its current rate. Another streamflow reconstruction was developed for the upper Gila River Basin in western New Mexico and eastern Arizona made by David Meko and Donald Graybill (1995). They used nine chronologies of five different species with a multiple linear regression to extend the streamflow record back to 1663. In an area where there is already not enough water, Meko and Graybill found that dry periods occur at irregular intervals of averaging about 20 years. Another recent study that is widely cited in the American Southwest is a reconstruction of the Upper Colorado River Basin by Meko, Woodhouse, and others, see Figure 6 (2007).

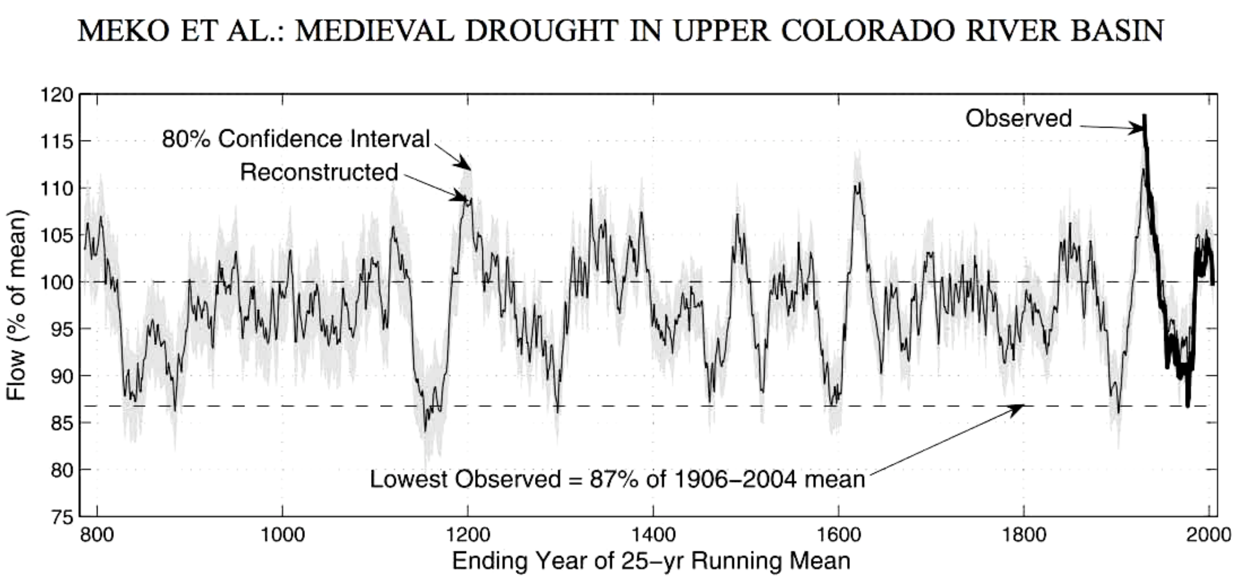


Figure 6. This is a graphical representation of Meko, et al.’s recontruction of the Colorado River streamflow in percent of annual mean flow at Lee’s Ferry, AZ back into the Medival Period (2007).

They used eleven *long* chronologies containing remnant and living wood with a multiple linear regression to extend the Colorado River streamflow at Lee's Ferry back to A.D. 762. They determined that the most severe drought of the reconstruction occurred the mid-1100's, characterized by a 15% decrease in annual mean over a 25 year period. They also established that this drought did not correlate with either of the two Sierra Nevada Mountain's 100 yearlong droughts, although it did occur during the time broadly referred to as the Medieval Climate Anomaly.

Dendrohydrologic reconstructions such as these are important to understanding our very limited water resources, especially in the semi-arid western U.S. These chronologies help water managers effectively plan for worst-case scenarios. Tree-Flow (http://treeflow.info/) is a website developed with the water manager in mind. This website provides easy access to streamflow reconstructions and information about their development and use. Tree rings help us educate others of the limits of our water resources and what we must do to secure them for the future.

III. Investigation of North American Monsoon Variability using Instrumental and Tree-Ring Data.

In this project, we are updating and re-analyzing high-quality, archived tree-ring collections from across the American Southwest. The updated chronologies will be used to reconstruct winter and summer precipitation, with a focus on summer-season precipitation variability as influenced by the North American Monsoon (NAM) system. These reconstructions will educate water users and distributors who rely summer-season precipitation to alleviate demand in a critically hot and dry time of the year. Furthermore, this project is exploring methodologies for future intra-annual tree-ring chronology development.

Although modern dendroclimatology originated in the U.S. Southwest, there has never been a comprehensive tree-ring study of summer-season precipitation associated with the North American Monsoon. This is surprising because the NAM is a critical source of moisture for much of the U.S. Southwest. The U.S. Southwest is on the northern end of influence for the NAM and receives from 30 to 50% of it's annual rainfall from the NAM. In northwestern Mexico, the monsoon is even more important because it provides nearly 70% of the annual precipitation (Figure 3, NSF Award 0823090). Much of the southwest relies on the summer-season precipitation to relieve pressure on the reservoirs to provide adequate water for agriculture and cities. In the especially warm climate of the southwest, the cool-season precipitation replenishes the soil moisture but only for a limited time in the winter and spring. The monsoon's rains come at a crucial point in the year, during the hottest months July and August, to ease pressure on the stressed water resources. Recent studies have helped us understand the NAM, but there is still very limited knowledge about its long-term precipitation variability and its phase relationship to cool-season precipitation.

Previous tree-ring reconstructions in the region have modeled either annual or cool-season precipitation, typically using the total ring width. However, the earlywood and latewood components of tree rings in the American Southwest can be used as a proxy for both cool season and summer season precipitation, respectively. Wood formed in the early part of the season, so-called earlywood, appears light colored due to large cells with thin cell walls, while wood formed later, latewood, appears darker colored due to smaller cells with thicker walls (Figure 7). Research has shown that the intra-annual latewood measurements can reflect summer moisture variability (Meko and Baisan 2001,).

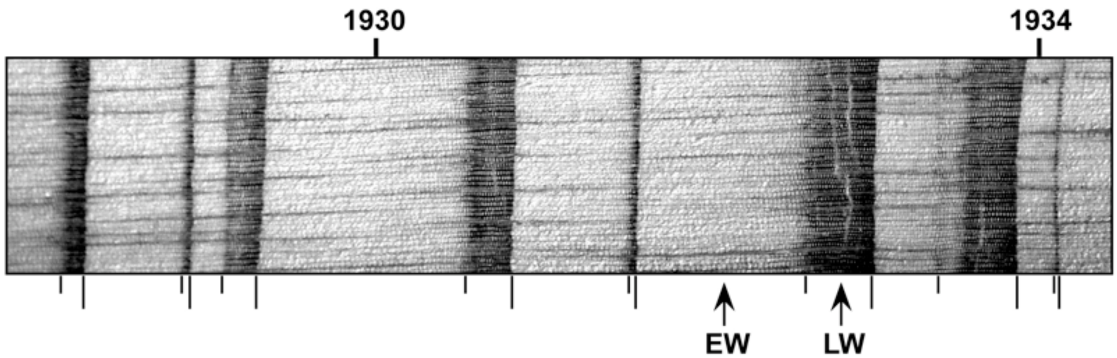


Figure 7. This is a close up photograph of a Douglas-fir sample illustrating the intra-annual components of the tree-rings: earlywood (EW) and latewood (LW). Notice the variability in earlywood-, latewood-, and total ring-width from year to year.

The goals of this research are to reconstruct and statistically characterize winter and summer drought history for the U. S. Southwest, focusing on the effect of the North American Monsoon. This project will investigate the NAM by updating and re-analyzing over thirty existing tree-ring chronologies (Figure 3). The intra-annual tree-ring widths for sites will be developed into site chronologies where they will be calibrated with precipitation data to model both early- and late-season precipitation. If successful, this research will not only improve understanding of NAM variability beyond the instrumental period, but it will test and improve the method of using latewood as a warm-season rainfall proxy.

The results of this project will have the potential to benefit many users of water in the American Southwest. The instrumental precipitation records of interest will be extended at least 300 years and give us a broader scope of the range of variability in the NAM. A better understanding of NAM precipitation during the hottest period of the year will help improve planning of water storage and distribution by water managers.

Additionally, this project is not limited to the elite scientific community. Several undergraduates at the University of Arizona and a high school intern from southwestern Colorado (me), will receive valuable research experience assisting in a significant scientific research project. Dan Griffin, a graduate student researcher, has received a Biosphere 2 Science and Society Fellowship where he will communicate our research and progress for this project to the public outside of an academic setting. Additional information will be available at the project web-page: http://monsoon.ltrr.arizona.edu.

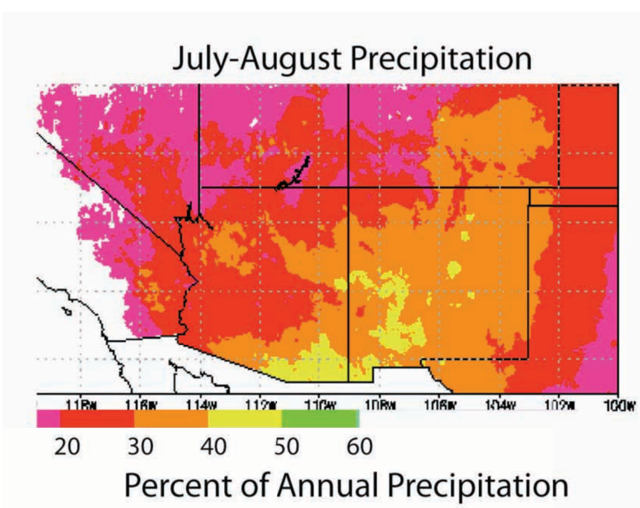


Figure 8. This is a map showing the July and August precipitation as a percent of the annual total. You can see in Southern Arizona and New Mexico the summer season precipitation provides a large percent.

IV. My Involvement

My name is Victor Major and I was an intern with the Laboratory of Tree-Ring Research at the University of Arizona through the Pinhead Institute. I have never done anything like this before. Before this six week program, the longest I had ever lived by myself was a day or two, and the longest I had been away from my family was a couple of weeks. My high school science career has been somewhat limited by living in a small town at the end of a box canyon, but my period under Dan Griffin at the Laboratory of Tree-Ring Research really opened my eyes to the scientific world.

For my first week, I helped Dan Griffin, Connie Woodhouse, and Mark Losleben do fieldwork in the extended four corners area (Figure 9). I learned and practiced tree-ring field techniques, everything from tree and site selection to increment borer use. I really enjoyed the fieldwork. Connie, Mark, and Dan were accepting and helpful to me, turning my inexperience into knowledge. We camped almost every night and spent the days either driving, eating, or hiking around the sites. The sites, especially White Canyon and Navajo National Monuments were fantastic. I was able to see more of the U.S. Southwest than I ever had before. I could have done fieldwork all summer, but unfortunately, this was not possible.

Figure 9. Connie Woodhouse, Mark Losleben, and I having a good time, taking a break at the White Canyon site in Natural Bridges National Monument in southeastern Utah.

For the rest of my work with Dan, and the exception of one day, I have been working in the lab below the University of Arizona football stadium. It has been interesting to see and be a part of the workings in the lab, even more so after the field work. I think that if I had not spent any time in the field I wouldn't appreciate the lab work as much. I was able to go from the actual trees in the field, to the lab where I was able to see individual cores, and eventually see and measure individual rings. In the lab, I worked mostly with sample preparation by inventorying and mounting cores from earlier field collections. I have also been coding data from the cores by measuring the earlywood and the latewood with the computer system and the stage micrometer. Dan introduced me to the concepts of cross-dating and the statistical analysis, but I didn't get to deep into those specialties. I toured the woodshop and would have liked to try it, but I was not allowed to work in the woodshop because of my age as a minor. I found that the labwork is very important to the scientific process, it is not all field work or big presentations, but a long procession with lots of effort involved. It might not be the most exciting, but it is interesting and enjoyable and the final product couldn't happen without it. And in the end, I contributed to the development of nearly 15 new tree-ring chronologies.

In addition to my time in the lab, I wrote three short papers and combined them into this document. For each paper, Dan had me read several professionally written and published papers, including one short book, on that subject in order to familiarize myself with that topic. Reading has always been a pretty good way for me to absorb large amounts of information, but writing about those subjects really sealed it into my brain. Some of the articles I read were published with the public in mind, others were chapters out of scientific texts or articles published in respected science journals. Once I was familiar with the scientific format and the language of dendrochronology, the papers became easier to read and understand. Moreover, Dan's editing, corrections, and good constructive criticism helped me find and improve my writing skills. Just in time for my senior year. Dan held me to a high academic standard, which I was not used too, that raised my bar as well.

My experience in the Pinhead Internship Program and at the Laboratory of Tree-Ring Research under Dan was a positive one. Academically, I absorbed a very large amount about the scientific process and dendrochronlogy in a short period of time. Something I would have never been able to get at my high school. Also, Dan's tough critiques on my writing helped fine tune my skills. He tried to keep me at his level as a graduate student. Furthermore, this internship gave me valuable research experience and connections I can use in the future. Most undergraduates don't get the research experience I was lucky enough to receive. Connie Woodhouse has offered to write a letter for me and Dan has filled my brain with his best scientific and personal advice. He shared his experiences and information from a perspective I would have never been able to find in our sheltered canyon. Also, working at a university helped me further understand what I want from college. For example, I know that I don't want to come to Tucson as an undergrad. Living on my own promoted my personal growth and maturity, and helped me appreciate my mom even more. I believe this experience was one that I always remember for the good things that I gained from it: knowledge, experience, friends, and maturity.

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