Name______________________
Date_______________________

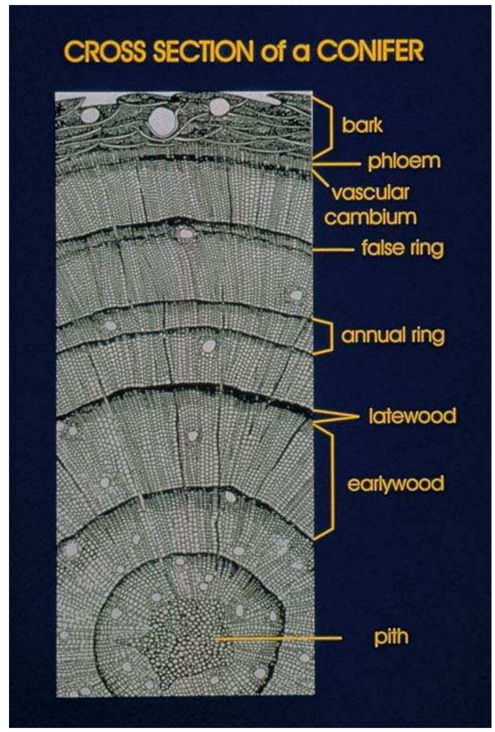
Introduction to Tree-Ring Research

A 2-week laboratory module

Developed by Park Williams

Introduction

Trees are wonderful things. Often living for centuries, or even millennia, they remain fixed in location, photosynthesizing and growing in response to a suite of environmental variables such as sunlight availability, temperature, relative humidity, soil conditions, competition, and availability of soil moisture. In regions with sufficient seasonality, one or more of these limiting factors generally causes growth to slow and eventually stop each year. In coniferous species, large xylem cells produced early in the growing season, called **earlywood** cells, are associated with periods of substantial soil-moisture availability, ideal temperatures, and rapid growth. The cells produced immediately before annual dormancy, called **latewood** cells, are relatively denser with thick walls that are important for structural support of the tree. These cells appear as annual dark rings on the cross-section of conifer and ring-porous angiosperm trees. The innermost ring represents a tree's first year of growth at a given height and the outermost ring represents the last year of growth.



The relative width of an annual tree ring is strongly influenced by the tree's growth rate during the year of growth. Growth rate is primarily dictated by limiting factors such as low temperatures at high latitudes and elevations, and by water stress in Mediterranean and semi-arid regions. Therefore, trees faithfully record environmental phenomena from year to year and represent the best records of annual climate variability prior to instrumental observations in many parts of the world.

In this lab you will learn:

1) the techniques used by *dendrochronologists* to assign dates to individual tree rings,
2) how tree-ring measurements can be used by *dendroecologists* to learn how forests function, and
3) how tree-ring measurements can be used by *dendroclimatologists* to understand past climate.

NOTE:

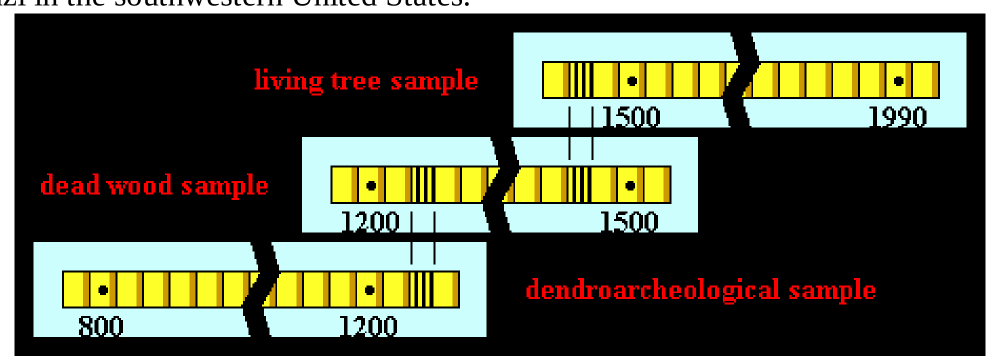
- **Bold** font indicates jobs to be completed and presented in your final report.
- A color version of this lab can be downloaded at: http://www.geog.ucsb.edu/~williams/fieldcourse/treeringlab/lab.pdf

Part I: Cross-Dating and Dendrochronology

Annual rings are visible in many trees, and they don't all look alike from year to year. Where environmental variables such as moisture, temperature, or fire affect all trees in a given region at the same time, it is common for the growth rates of most trees in that region to respond similarly. For example, in arid regions, trees generally grow more during wet years than they do during dry years. This causes rings that develop during wet years to be wider than those grown during dry years in drought-limited trees.

If we collected a core sample from a living tree, rings can easily be counted from the outside (where the bark is) toward the inside (where the pith is) and a year can be assigned to each ring. Often times, however, dendrochronologists work with wood from trees that died an unknown number of years ago. This is when pattern matching becomes important. If the pattern of thick and thin tree rings from a portion of a tree core of an unknown age matches the pattern of part of a tree core of a known age from the same region, we know that the two trees grew simultaneously. This cross-comparison of tree-ring patterns is called *cross dating*

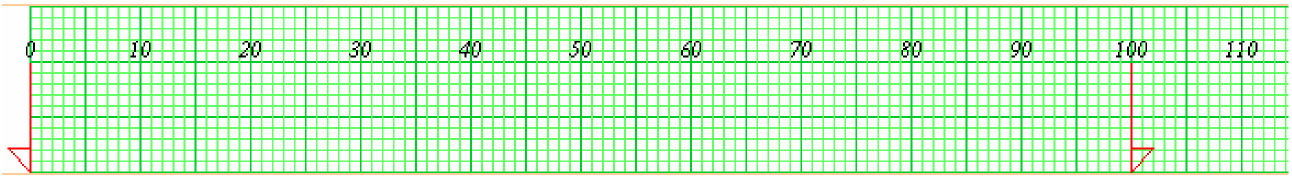
Think of a tree core collected from a living 80-year-old Torrey pine tree from Santa Rosa Island, CA in 2007. Counting back from the newest ring (2007), you would find that the core displays thin rings grown during the droughts 1988-1990, 1976-1977, and 1946-1951, and thick rings during wetter years. Now imagine a second core that was collected from a dead tree trunk in the same forest. Because that tree was dead when the core sample was taken, you are unsure of knowing during which year the outer ring grew. However, you notice that the 5th ring in from the outside is abnormally thick, the 8th-9th rings are skinny, the 33rd-38th rings are skinny, the 42nd – 43rd rings are thick, and there are 90 total rings present in the sample. By pattern matching, you would find that the thick fifth ring corresponds to the rainy year of 1979, the thin 8th and 9th rings match with the 1976-1977 drought, the 33rd-38th rings match with the 1946-1951 drought, and the 42nd and 43rd rings correspond with the rainy years of 1941 and 1942. You could then infer that the most recent ring from the dead tree grew in 1983 and the first ring grew in 1890. A visual representation of this concept is below. Through cross dating, dendroarchaelologists have been able to tell how long ago buildings were built in many historical societies including those of the Anasazi in the southwestern United States.



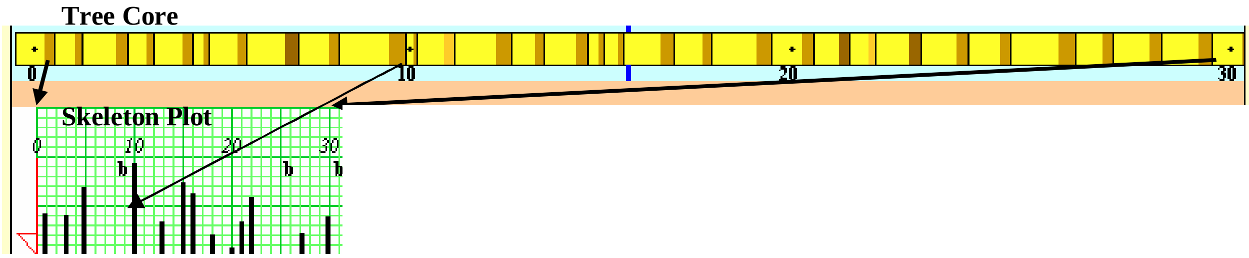
Skeleton plotting

It is generally difficult to find matching patterns in tree rings by simply comparing two tree cores side by side because two cores with the same amount of rings usually differ in length. An easy way to get around this problem is to plot on graph paper where within a core thin and thick rings exist. This technique is called *skeleton plotting* and was invented by Andrew E. Douglas, the founder of dendrochronology, in the early 1900s.

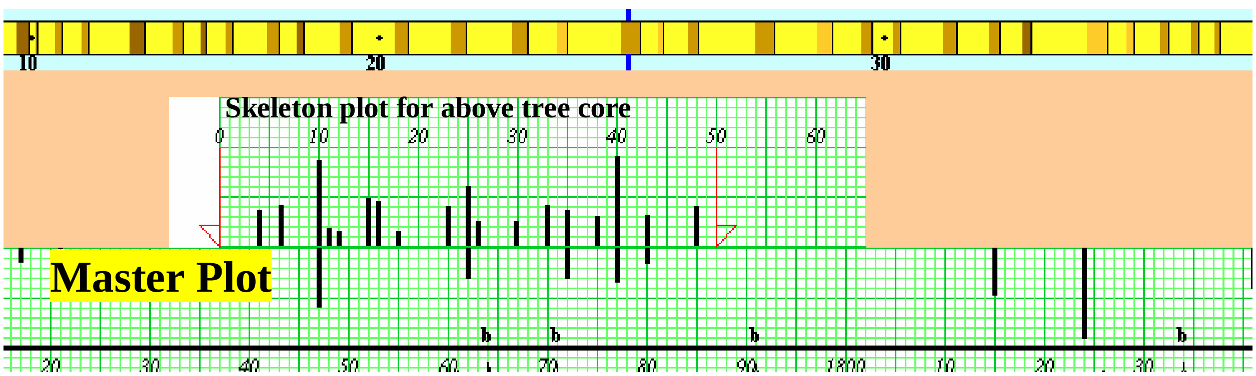
Below is an example of skeleton plot graph paper:



Widthwise, each grid cell represents one annual tree ring. Height wise, dendrochronologists mark vertical lines to represent tree rings that are skinny relative to the several surrounding rings. Taller lines represent skinner rings. An abnormally thick ring is marked with a “b” for big. Below, rings 9, 26, and 31 were indicated as thick rings.

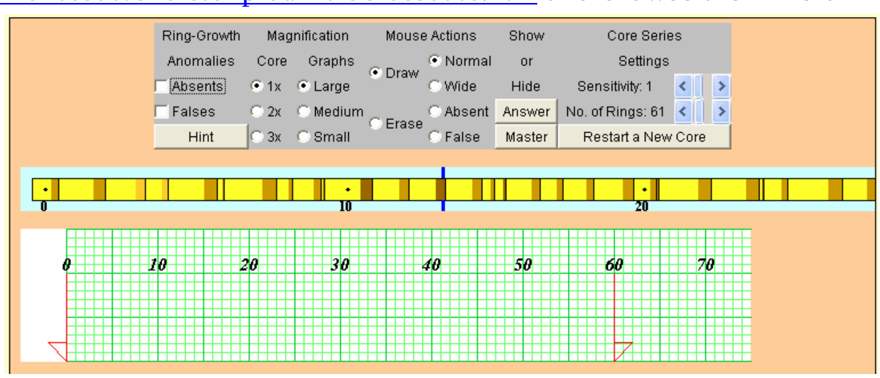


Once skeleton plots have been made for several cores of known age, a master skeleton plot is developed. The master skeleton plot is denoted with actual years instead of tree-ring numbers and is upside down so that it can be easily compared to skeleton plots of cores for which the age is unknown.



Exercise #1.1: Intro to skeleton plotting and cross dating

1) Log on to http://www.ltrr.arizona.edu/skeletonplot/introcrossdate.htm and browse the links on this website as much as you please. When finished, click on “12. Try Skeleton Plotting for Yourself!” The center of your internet browser window should look like this:



2) Click on the right arrow next to “No. of Rings: 61” to turn the number of rings up to 131.

3) Click “Restart a New Core”

4) Below the grey control panel is an illustration of a tree core. The oldest ring (ring #0) is on the left, as you can tell because the darker latewood bands are on the right edges of the rings. You do not know the age of this tree core. The numbers only label # of rings to the right of ring #0. You can make the tree core slide back and forth by clicking on the tree core and dragging it in the direction you want it to slide. Try it.

5) Below the tree core is your skeleton plot graphing paper. The numbers on the skeleton plot refer to ring numbers, not years. The two upside-down flags represent the first and last rings of the core. You can make the skeleton plot slide back and forth by clicking on the upper part of the paper (above the numbers) and dragging your mouse back and forth. Try it.

6) Skinny rings are marked on the skeleton plot by a vertical line. Click once in the lower two-thirds of the skeleton plot and make a vertical line. Taller lines represent very skinny rings, shorter lines represent kind of skinny rings. You can control how short or tall your line is by clicking low or high on the chart.

7) You can erase lines by clicking “Erase” in the “Mouse Actions” portion of the control panel up top and then clicking back on the line that you just created on the skeleton plot. Erase the line you created in the last step. Now click back on “Draw” in the “Mouse Actions” menu.

8) Abnormally wide rings are marked on the skeleton plot by a “b.” Under “Mouse Options” click on “Wide.” Now click back on the skeleton plot on a ring number that corresponds with an abnormally wide ring on the tree core. By clicking back on “Erase” and then clicking the “b” that you just created, you can erase the “b” if you need to.

9) Under “Magnification,” you can change the magnification of the core and/or skeleton plot if you like.

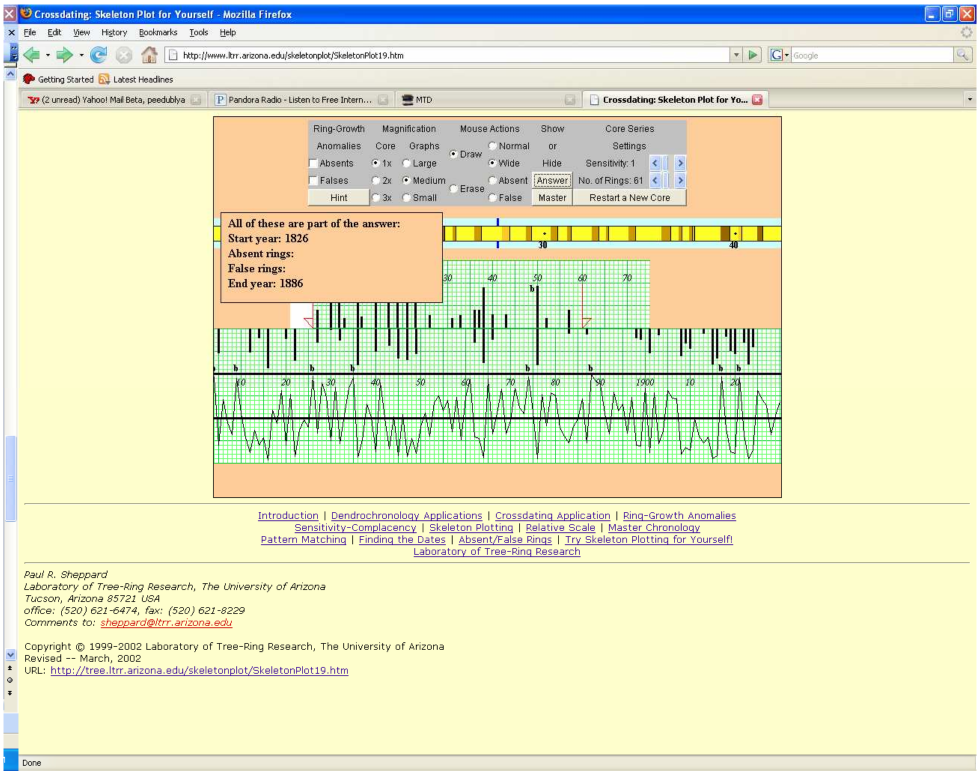
10) Create a skeleton plot for your 131-ring core. When deciding whether a ring is thick or thin, compare it to the 6 - 10 rings immediately around it.

11) When the skeleton plot is complete, click on the “Master” button below “Show or Hide.” This will open a master skeleton plot and a graph of ring-width indices below your skeleton plot. Don’t worry about the ring-width indices for now. The master plot was created from many tree cores with known ages from the same area as your tree core and spans many more years than your single tree core. You can slide the master plot back and forth.

12) Slowly slide your skeleton plot and master plot back and forth until you think that you see a good match in patterns of skinny rings. It may help to change the magnification of your plots to “medium” or “small” to see more years at once.

13) Once you’re confident in your cross-dating, click on “Answer” under “Show or Hide” and see if you dated your tree core correctly. If you were incorrect, click on “Answer” again to hide the answer and either keep working or start over.

14) Once you have a correctly dated skeleton plot, press the "Print Screen" key on your keyboard. This copies everything shown on your monitor. **Paste this picture in your final report.** An example is below:



Exercise #1.2: Advanced skeleton plotting and cross dating

The following page shows a magnified tree core split into four pieces. It was collected from a Torrey pine tree on Santa Rosa Island. As in the previous exercise, the oldest rings appear on the left, more recent rings on the right. The top segment comes from the outermost part of the tree (most recent) and the lower segments come from progressively inner (older) parts of the tree.

1) **Use the skeleton plot graphing paper provided to create a skeleton plot for the 45 rings displayed.** All rings are bounded by small white lines on the bottom of the core. Note that the most recent ring (top segment, rightmost) is only a partial ring because this core was collected in the middle of the growing season (May).

2) **Do you have any guesses as to what the start and end years may be? How might you figure this out if you don't have a master skeleton plot to compare to?**

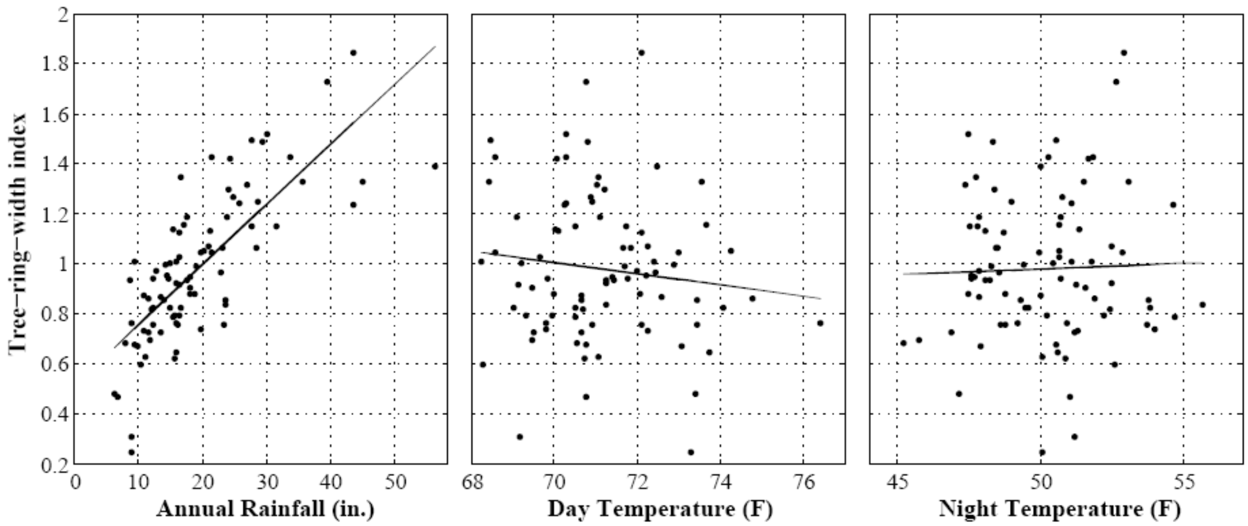
3) **Upon completion, compare your skeleton plot to the longer, master skeleton plot provided by your instructor (created using 30 Torrey pine cores) and determine the beginning and end years for this core.**

TOP

Part II: Dendroecology

As you saw in the last section, tree growth can be extremely sensitive to changes in environmental conditions from year to year. Which environmental parameter do you think the Torrey pine tree on the previous page is most sensitive to? Rainfall? Temperature? Wind? Soil nutrients? Grazing by elk? Fire? Dendroecologists answer questions like this by comparing annual tree-ring widths to various annual climate records collected by nearby weather stations. To do this, they first precisely measure all tree-ring widths from many tree cores and convert the width data from all cores into one average ring-width record. Because tree-rings generally become thinner as the tree becomes wide, the ring-width record from each tree core is first converted to standardized "ring-width index" values with a mean equal to one. You will not deal with standardization in this exercise, but you will work with tree-ring index data.

The set of plots below shows how Torrey pine ring widths (*y*-axes) relate to three climate variables (left: annual rainfall; middle: daytime high temperature; right: nighttime low temperature).



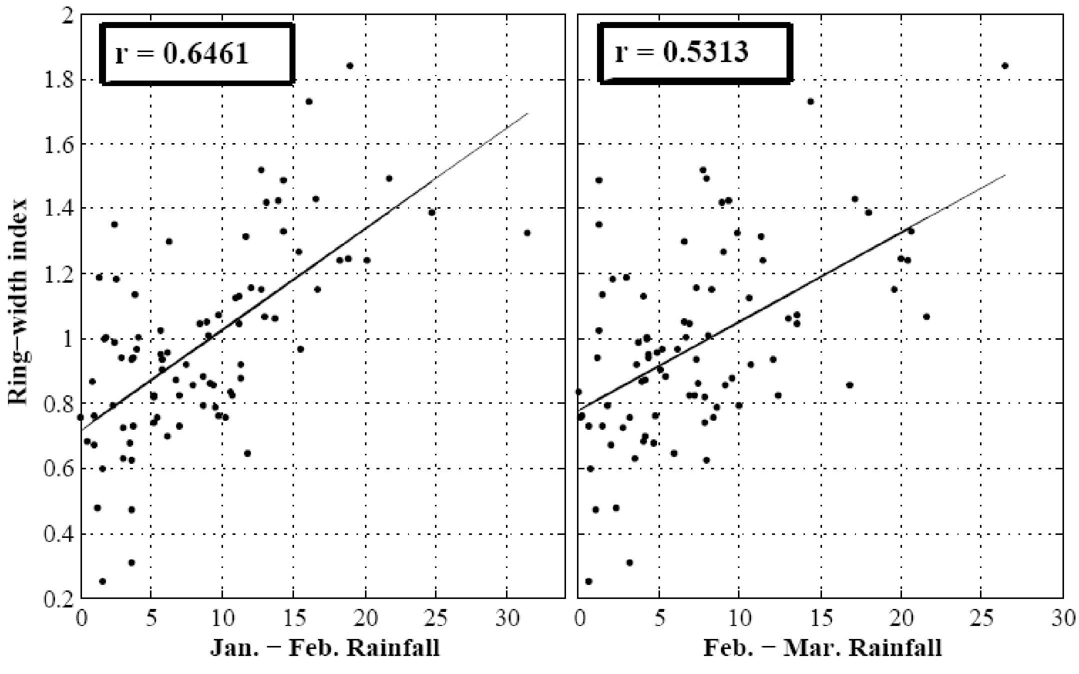
From these plots, you can clearly see that Torrey pine trees on Santa Rosa Island tend to grow more in years of high rainfall than in years of low rainfall. However, this relationship is not perfect, meaning that rainfall does not dictate 100% of interannual variation in tree growth. If the relationship were perfect, all points on the left graph would line perfectly on the black trend line.

By comparing the three plots, you should easily see that the relationship between rainfall and tree growth is much, much stronger than the relationship between tree growth and annual temperature. This is *dendroecology*: using tree rings to tell us something about the growth dynamics of a vegetation system. A dendroecologist would probably interpret the above plots like this: "*Growth of these trees is clearly limited by drought, as indicated by the strong positive relationship between tree-ring index values and annual rainfall. This is consistent with what we know about vegetation in southern California. It also looks like, from the very low values of the leftmost points on the left plot, trees especially suffer from drought in years with less than 10 inches of rain. While high temperatures can also decease water availability due to increased evaporation, it makes sense that temperature does not limit tree growth because temperature does not vary much from year to year in this coastal environment. Annual rainfall, on the other hand, is much less consistent.*"

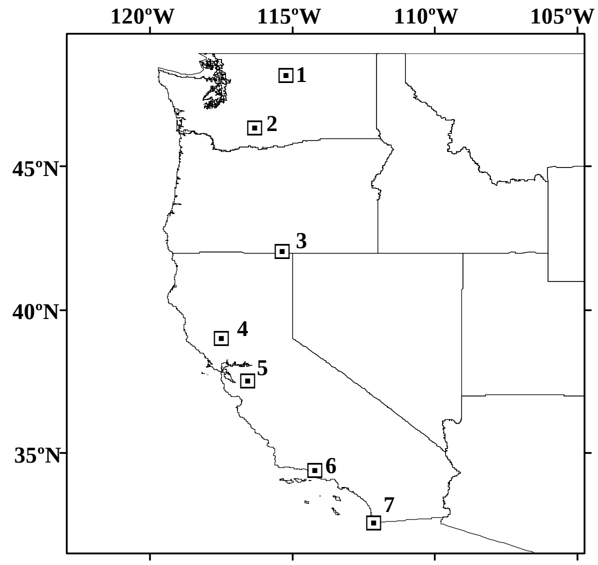
Testing the statistical strength of a relationship

From the above plots, we can clearly see that the relationship between rainfall and ring-width index is strong. However, it is often necessary to evaluate a relationship's strength statistically. For example, if you wanted to tell whether January through February or February through March rainfall has the stronger relationship with tree growth, you may not be able to tell by simply comparing the scatter plots as we did on the previous page. One way to evaluate the strength of a relationship is to calculate a *linear correlation coefficient* (r). The statistics underlying the calculation of r will not be covered in this lab, but you will use Microsoft Excel to calculate quite a few correlation coefficients. The important parts to understand are that r values are always between -1 and +1. When $r = 0$, there is no relationship between the two variables in question. When $r = +1$, the relationship is perfectly positive. This means that as one variable (say rainfall) increases, the other variable (ring width index) increases proportionally 100% of the time. When $r = -1$, the relationship is perfectly negative. As one variable increases, the other variable decreases proportionally 100% of the time. In nature, there is no such thing as a perfect ($r = 1$ or -1) relationship. Instead, there are trends or tendencies. For example, when there is an abnormally wet year, Torrey pines on Santa Rosa Island tend to grow more. This is an imperfect positive relationship that would be described by a correlation coefficient that falls somewhere between 0 and 1.

The plots below show the relationships between ring-width index and (left) January – February rainfall and (right) February – March rainfall. While the graphs look similar, the correlation coefficients indicate that Torrey pine growth on Santa Rosa Island is likely more responsive to early winter rainfall than late winter rainfall.



Exercise #2.1: ***Dendroecology in the western United States***



In this exercise you will evaluate how the relationships between climate and tree growth can vary geographically. For example, Torrey pines on Santa Rosa Island can be expected to be sensitive to different climatic factors than a forest at the northern tree line of Canada or Siberia. This concept is described in your assigned reading: *The Nation States of Trees* by Paul Colinvaux.

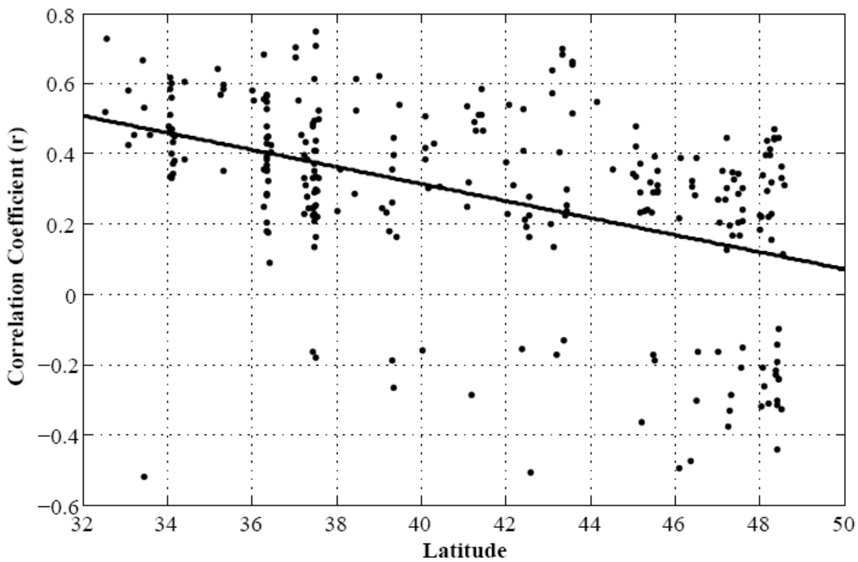
To begin this exercise click here, or go to: http://www.geog.ucsb.edu/~williams/fieldcourse/treeringlab/TreeRingLab.xls. Save this file to your computer. This is a Microsoft Excel file with two spread sheets. One spreadsheet is titled "RingWidths" and the other is "Rainfall." You can flip back and forth from these two spreadsheets by clicking on the titled tabs at the bottom-left side of the spreadsheet. The *RingWidths* spreadsheet contains annual ring-width index values for each of the seven sites, along with the latitude, longitude, and elevation of each site. These datasets were downloaded from the International Tree-Ring Data Bank (http://www.ncdc.noaa.gov/paleo/treering.html). Note that the chronologies vary in length. The *Rainfall* spreadsheet contains annual October – September cumulative rainfall totals for the region from which each tree-ring record comes. These datasets were created by the National Climate Data Center (http://www1.ncdc.noaa.gov/pub/data/cirs/) and represent regional averages compiled using many weather stations. This is why the rainfall datasets for sites 6 and 7 are identical: they both fall in the coastal southern California climate region.

1) For each site, use Excel to make a separate scatter plot of ring-width index (*y*-axis) versus rainfall (*x*-axis) like the ones on the previous page. Remember that the ring-width index data cover more years than the instrumental rainfall data. For the sake of organization, you may find it useful to open a new Excel spreadsheet and paste the ring-width and rainfall data side-by-side before creating each plot.

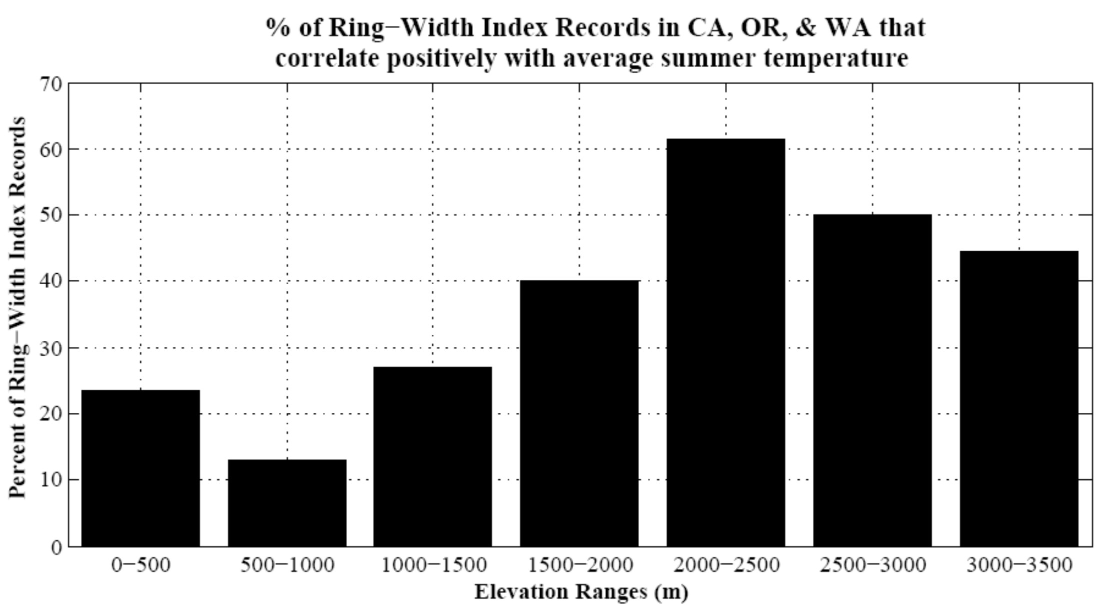
2) For each of these seven plots, add a trendline. To do this, highlight the scatter points (left-click on one of the points), then right-clicking and choosing "Add Trendline." In the *Add Trendline* menu, choose *Linear* and then click on the *Options* tab. Under *Options*, check the box next to *Display R-squared on chart*. Then click *OK*. Be sure to make the R-squared values large enough to read on your plots. The R-squared value is simply the *correlation coefficient* (*r*-value) multiplied by itself. **Include each of these graphs in your final report**.

3) Create a line graph showing how the previously calucluated R-squared values (*y*-axis) relate to latitude (*x*-axis). There should be one point for each of the seven sites analyzed. **Include this graph in your final report**. **What is the general relationship between R-squared values and latitude?**

4) The figure below is like the one that you just made, but for all 261 tree-ring chronologies from California, Oregon, and Washington published in the International Tree-Ring Data Bank. Note that the y-axis below shows *r* values rather than R^2. This allows us to observe negative relationships. As you can see, the relationship that you observed between latitude and the correlation coefficient describing the effect of interannual variation in rainfall on tree growth is real. **Why is this?**



5) Another commonly evaluated climate parameter in dendroecology is temperature. The bar graph below divides the 261 published tree-ring collection sites in California, Oregon, and Washington into seven equally sized elevation classes and shows that the percentage of ring-width index records that correlate positively ($r > 0$) with summertime temperature is lowest at low elevations. **Why are trees more likely to correlate positively with summertime temperature at higher elevations?**



Part III: Dendroclimatology

Across much of the globe, humans have been keeping regular and accurate records of climate for much less time than trees. Trees that are the best recorders of climate variation are the trees most affected by one or two single climate variables. Tree-ring widths in arid regions like the southwestern United States are often dominated by annual rainfall while trees at extremely high elevations have been observed responding to changes in temperature. Additionally, there are many locations, such as the northeastern United States, where tree growth tends to respond to various climate parameters at once. In dendroclimatology, the most useful trees are the ones for which growth is very sensitive to only one climate variable. This way, the dendroclimatologist can be confident in what causes a narrow or wide tree ring. When tree rings only significantly respond to one climate parameter, we can look at tree rings that grew well before the presence of weather stations and get a pretty good idea of what climate was like when those tree rings grew.

Exercise 3.1: Reconstruction of annual rainfall in central California

As paleoclimatologists, we are going to imagine that the only thing that affects ring width at Site 5 is rainfall. We will then calculate what annual rainfall totals should have been from 1645 through 1997, given that we know how much trees grew during those years. While it is obvious from looking at your scatter plot and R-squared value from Site 5 that annual rainfall is not the only thing affecting tree growth at Site 5, rainfall affects tree growth more than any other single climate variable. The long tree-ring record from this site will allow us to learn much more about long-term regional rainfall patterns than we would from the 111-year instrumental rainfall record alone.

1) Create a plot like the one you made for Site 5 in the previous exercise, but this time put *Ring-Width Index* on the *x*-axis and *Rainfall* on the *y*-axis. Again, add a trend line and display the R-squared value. Also, when adding the R-squared value, add the equation for the trend line by checking the box next to *Display equation on chart* in the *options* tab. Make sure that the R-squared value is the same as it was for Site 5 in Exercise 2.1. **Include this plot in your final report**.

2) The equation of your plot represents: Rainfall = (slope) x (Ring-Width Index) + intercept. This is the equation that you will build your rainfall reconstruction model from.

3) For each year that ring-width index data exist from Site 5 (1645-1997), use the above equation to calculate the estimated rainfall amount for California climate region #5.

4) Create a plot of estimated rainfall (*y*-axis) versus year (*x*-axis). Overlay actual rainfall versus year on the same plot. **Include this plot on your final report**.

5) **How can we better our understanding of rainfall patterns in California's central valley by extending the rainfall record as we just did?**