The Relation of Precipitation and Annual Tree-Ring Growth of Douglas-Fir in Stands of Different Ages in the Western Oregon Cascade Range

by

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Abstract

The extent to which precipitation has an impact on annual ring-growth of Douglas-fir trees and how that impact differs between stands of different age classes has been a little-studied topic, particularly in the Pacific Northwest. Three stands of different ages (young, mature, and old-growth) containing Douglas-fir located in the western Oregon Cascade Range near Blue River, Oregon were cored and measured. Tree-ring width records within each stand were crossdated, and standardized ring-width chronologies for each stand were created using standard tree-ring methods. Significant correlations between precipitation and recent growth histories of each stand were determined using DendroClim2002. Precipitation data were obtained from a meteorological station located in the young stand within HJ Andrews Experimental Forest. Significant correlations differed between stands of different ages. Positive significant correlations occurred between ring-widths in the mature and old-growth stands with June and October monthly precipitation values. The young stand showed significant negative correlations with precipitation in October and November of the previous year and February precipitation of the current calendar year. When precipitation data were modified by altering outliers, correlations changed idiosyncratically by month suggesting the modification was not extensive enough or irrelevant. When a long growth history from the old-growth stand was correlated with precipitation data, the most significant correlations were with monthly precipitation in April and June of the current year and July of the previous year. These correlations suggested that precipitation in the form of rain, particularly around the months on either end of the growing season, have

significant relation to tree-ring growth. In addition it was discovered that ring growth in young stands react negatively to precipitation whereas mature and old-growth stands have positive correlations between ring growth and precipitation.

1. Introduction

There are several environmental factors that place key limitations on the growth of Douglas-fir (*Pseudotsuga menziesii*). They include nutrient and mineral availability, ambient air temperature, and water availability. Throughout the Oregon Cascade Range despite great amounts of annual precipitation, summers are dry and water availability is a particularly limiting factor in vegetative growth (Waring & Franklin 1979). Physiologically, Douglas-fir trees have a maximum rooting depth in natural soils of approximately 0.9 meters with an error of +/- 0.1 meters (Heilman 1990). As such, these trees are not considered a particularly deep rooting species of tree (Burns & Honkala 1990). When growing in loose soils, roots of the Douglas-fir grow rapidly with the taproot reaching nearly its maximum length in the first ten years of growth. Commonly, in addition to the initial taproot, some roots are found near the mineral soil surface or in the organic soil layer, making absorption of water from precipitation following water stress very rapid (Burns & Honkala 1990). Precipitation quantity and monthly distribution is variable year to year depending upon local and regional weather patterns, making it a prime candidate for an environmental factor that has a significant bearing on annual tree-ring growth.

During the late 1920s through the early 1940s several studies were carried out throughout the United States on a variety of tree species attempting to correlate climatic variables – temperature and precipitation in particular – with tree-ring growth (Douglass 1914, 1922; Diller 1935; Hansen 1941). With a variety of tree species and location studied, there have been significant correlations identified between tree growth and everything from solar variations to temperature and precipitation (Douglass 1922; Diller 1935). Studies comparing correlations between species and specific climate factors have also identified a varied strength in response between ring width growth in species and climate factors (Hansen 1941).

More recently, throughout the Pacific Northwest tree-rings have been utilized as a means by which both droughts – via the Palmer Drought Severity Index – and streamflow can be reconstructed (Woodhouse 2006). Likewise, studies have been carried out that attempt to correlate precipitation variation with ring-width growth in Douglas-fir in Vancouver, B.C. and south through the Pacific Northwest of the United States (Zhang & Hebda 2004; Graumlich 1987; Watson & Luckman 2002). In British Columbia, across different elevations, temperature and growing season precipitation have been identified as having significant correlations with Douglas-fir growth on a macro-regional scale (Zhang & Hebda 2004). Although several studies have been carried out, the environmental controls of Douglas-fir growth in the western Cascade Range has been largely untapped as a research topic.

The specific objectives of this study were to: (1) create chronologies for the study area, and (2) determine to what extent precipitation has an impact on annual ring-growth of Douglas-fir trees and how that impact differs or is similar between stands of different age classes. The knowledge gained from this study will help with the reconstruction of past precipitation using tree-ring records of extremely long-lived Douglas-fir trees.

2. Study Area

Data were collected from three locations, encompassing stands of three different ages: young, mature, and old-growth. Two sites, the young and old-growth sites, are located within HJ Andrews Experimental Forest Long-Term Ecological site, while the other, mature stand, is located near Cougar Dam, less than one kilometer from the HJ Andrews Experimental Forest on the South Fork of the McKenzie River. The study area is characterized by a maritime climate encompassing mild, wet winters, and cool, dry summers. Mean monthly temperatures range from approximately 0.6 °C in January to 17.8 °C in July. Over the past 45 years, a minimum of 90% of the years have had October 22 or earlier as the first month during which a freeze (minimum temperature below 0 °C) occurred. Likewise, a minimum of 90% of the past 45 years have had their last freeze (0 °C or lower) by June 4 (Oregon Climate Service). Following the standard definition, June to October is the growing season for the area within which all three stands are located. Precipitation falls primarily November through March, at roughly 230 centimeters per year, with only 6% falling between June and August (Bierlmaier & McKee 1989). Elevations range from approximately 400 meters to 1080 meters in all three study areas.

The young stand was located within watershed 1 (WS01) which has a history of disturbance. During 1962 to 1966 the 96 hectares of WS01 was clearcut using a high lead cable system which did not require the creation of roads (Lutz & Halpern 2006). During October of 1967 WS01 was aerially seeded, and 10 hectares were reseeded in October of the following year. Establishment was found to be poor resulting in the planting of 2 year old Douglas-fir seedlings at 3 meter spacing in April and May of 1969. Due to poor survival over 40 hectares of the South-facing slope, two years later, in April of 1971, seedlings were planted once again at 2.4 meter spacing. It is unknown the contributing proportions of natural and artificial regeneration of the Douglas-fir trees (Lutz & Halpern 2006).

The mature stand at Cougar Dam has little known history although due to proximity it likely has had a similar fire disturbance history as the stands within HJ Andrews Experimental Forest, followed by logging in the late 1930's, as estimated from the ages of trees. Upon visual inspection there is evidence of thinning and other forest management practices, possibly resulting in asynchronous growth release events throughout the stand.

The old-growth stand, watershed 2 (WS02) within HJ Andrews Experimental Forest, likely regenerated following the catastrophic fires that engulfed the west coast of North America during the 1500s, although it is likely portions burned again during widespread wildfires in the 1800s (Teensma 1987).

Hereafter the young stand in WS01 shall be Stand Y, the mature stand near Cougar Dam shall be Stand M, and the old-growth stand in WS02 shall be Stand O.

3. Methods and Materials

3.1 Sampling Strategy

Trees from which samples were taken held the following criteria: Douglas-fir, near the trail (WS01 and WS02 only), less than two trees within a 1.5 meter radius, healthy looking crown, no visible scaring or other damage, and approximately 50 meters away from the last tree cored. Proximity to trail was an important factor for choosing trees located within HJ Andrews so as to not disturb permanent plots and long-term research sites.

Cores were taken between 22 February 2007 and 27 March 2007 using an increment borer. Trees were cored primarily from their uphill side at breastheight – approximately 1.5 meters above the ground. Forty-five cores were collected, fifteen from each of the three stands. Increment cores were stored in straws for transport back to the laboratory for mounting and measurement.

Cores were individually mounted in routed out blocks of wood with standard white school glue. A clean, flat, readable surface was created using a handheld orbital sander and increasingly fine grits of sandpaper.

In order to date the trees, tree-rings of each core were counted under a dissecting microscope with 20x magnification marking decades, half-centuries, and centuries in pencil. Ring-widths were measured by hand using the computer program Measure J2X, a measuring table, and a microscope with 40x magnification. Rings were measured for their annual growth to the nearest micrometer.

In order to accurately crossdate samples, the computer program COFECHA was employed using the files generated by Measure J2X as input files. COFECHA works by detrending data by fitting a 32-year spline to the growth curve which is designed to retain 50% of the variance in the tree-ring series (Grissino-Mayer 2001). The program was set to examine succeeding 25 year segments with an overlap between segments of 5 years. Autoregressive modeling was employed when processing the measurement data such that residuals were used in master dating and testing. This was done so as to remove persistence that may still remain after the spline has been fit to the curve and detrending (Grissino-Mayer 2001). Between detrending, fitting a spline, and autoregressive modeling the outcome is the removal of most or all of the low-frequency trends (Grissino-Mayer 2001). Based on the output of COFECHA several tree-cores were altered and/or modified to increase crossdating accuracy. Once crossdating was finalized, sample 12 from Stand Y was excluded from further inclusion within the study due to inexplicable growth morphology. The interseries correlation was 0.309 for Stand O, 0.344 for Stand M, and 0.328 for Stand Y.

Following crossdating, the computer program ARSTAN was employed to detrend each series and create master tree-ring chronologies. The samples were truncated to growth occurring between 1980 and 2006 so as to create chronologies of comparable segment length and then detrended. Stand O was also truncated and detrended for the years 1930-2006 so as to match chronology length and the period of available climate data. During the detrending process a general negative exponential curve was fit to each crossdated series. Multivariate autoregressive modeling was performed on the detrended data, followed by univariate autoregressive modeling. The resulting residual series then had multivariate autoregressive modeling performed on it to “determine if residual multivariate lag effects remain” (Holmes & Cook 1986). Three different chronologies are created following this process. First, the standard chronology was produced which is simply the detrended ring-widths. Second, the residual chronology was created from univariate autoregressive modeling. A mean value function of all of the residual series within a stand was created from the detrended tree-ring index series (Holmes & Cook 1986). This chronology is characterized as containing only year to year variability, having removed long-term trends. Third, the ARSTAN chronology was created by reincorporating the autoregression model into the residual chronology. Of the resulting chronologies, the ARSTAN chronology was the focus of most analyses because it is purported to contain the strongest climatic signal possible (Holmes & Cook 1986). The residual chronology was also employed for analysis of Stand O. The raw data chronology for each stand had a mean sensitivity of 0.097 for Stand O, 0.094 for Stand M, and 0.090 for Stand Y. The raw data chronology for Stand O over the years 1931-2006 had a mean sensitivity of 0.096.

3.1.1 Correlation

Significant correlations between mean monthly temperature data from CS2MET and the ARSTAN chronology for each stand were determined using DendroClim2002. Ultimately, analyses of temperature data were not pursued due to the emergence of much stronger correlations with precipitation data, and for limiting the scope of this study.

Correlations between the ARSTAN chronology for each stand and precipitation data from PRIMET were found using the response and correlation analysis of DendroClim2002. The response and correlation function of DendroClim2002 uses a bootstrapping technique to calculate significant (>95%) correlations between the calculated monthly precipitation values from PRIMET and tree-ring chronology throughout the time series (1980-2006). Each bootstrap estimate is created by the generation of 1000 samples selected at random with replacement, followed by running numerical calculations (Biondi & Waikul 2004). The ARSTAN chronology and the more strongly detrended Residual chronology for each stand were correlated with the total monthly precipitation for each month of the current and previous year, as well as a modified monthly precipitation (described below) for each month of the current year and previous year.

Precipitation data from Cascadia, Oregon spanning the years of 1931-2005 was correlated separately with the ARSTAN and Residual chronologies for Stand O. The response and correlation function of DendroClim2002 was employed to determine significant correlations with total precipitation for each month of the current and previous year.

3.2 Climate Data

3.2.1 PRIMET Precipitation Data

Daily precipitation data from 1980-2005 were taken from HJ Andrews' primary meteorological station (PRIMET) which is located within WS01 at approximately 44.212 degrees North, 122.256 degrees West, at 430 meters of elevation (McKee et al. 1997). Precipitation is measured at 100 centimeters above ground level. Monthly precipitation data was summarized from daily measurements using pivot tables in Microsoft Excel.

3.2.1.1 Modification of PRIMET Precipitation Data

Precipitation data was later modified in order to remove outliers and decrease the impacts of flood and/or drought events on the data. The data was modified by finding the mean precipitation for each month based upon the precipitation data available for the time series. Outliers were then identified on a month by month basis as the data points which lay greater than two standard deviations away from the mean. Values identified as outliers were replaced with the value of one standard deviation from the mean in the same direction of the outlier (+ or -). In all, throughout the time series fourteen values were identified and replaced (Table 1).

3.2.2 Cascadia, Oregon Precipitation Data

For a longer time series (1931-2005), daily precipitation data were used which were collected in Cascadia, Oregon at 44.4 degrees North latitude, 122.483 degrees West longitude – approximately 30 kilometers NNW of HJ Andrews Experimental Forest – at an elevation of 262 meters (Joint Institute for the Study of the Atmosphere and Ocean). The meteorological station is number 351433 of the National Weather Service's Cooperative Station Network. Monthly precipitation data was summarized from daily measurements using pivot tables in Microsoft Excel.

3.2.3 Temperature Data

Daily mean temperature data for the years 1972-2006 were obtained from HJ Andrews' Climatic Station (CS2MET) located in WS02. CS2MET is located at approximately 44.232 degrees North latitude, 122.249 degrees West longitude at an elevation of 485 meters (HJ Andrews Website). Temperature measurements were taken at a height of 130 centimeters. Monthly temperature data was summarized from daily measurements using pivot tables in Microsoft Excel.

4. Results

4.1 Chronologies

4.1.1 Recent Growth Chronologies

Stand Y's ARSTAN chronology (Figure 1: 1b) stayed relatively near the index value of 1 from roughly 1980 to 1995 with the majority of deviations having been less than +/- 0.05 except for 1984. In 1995 a decrease in index values began and continued until the lowest index of the chronology occurred in 1999. By 2002 the indices were rather positive once again. The greatest positive index occurred in 2005 before dropping down once again to an index value of nearly 1 in 2006.

The residual chronology for Stand Y (Figure 1: 1c) was a slightly less smoothed version of the ARSTAN chronology. Index values hovered around 1 for much of 1986 through 1995, before dropping in 1996 and staying constant in 1997. 1998 was characterized by a slight recovery from the low indices, followed by a drop to the lowest index of the chronology in 1999. The index values for 2001 and 2005 were the highest for the chronology. 2003 was a low index year between these two peaks, falling below 1. 1985 was also a low index year, with a value of less than 0.9.

Stand M's ARSTAN chronology (Figure 1: 2b) had a series of low index years from 1985 to 1989. There was a high index value in 1992 followed by a local minimum three years later. This pattern of high and low index values repeated with a local maximum or minimum occurring roughly every two years.

The residual chronology for Stand M (Figure 1: 2c) had a low index period from 1985 to 1989. A small movement toward a value of 1 occurred in the years 1986 and 1987, before decreasing again. From 1995 through 2006 a series of local maxima and minima occurred, starting with a local maximum in 1995. There were roughly two years between a local maximum and minimum until 2003 when the frequency changed to roughly one year between local maximum and minimum.

Stand O's ARSTAN chronology (Figure 1: 3b) started out with a high index (greater than 1) until 1985 when a period of quite low indices lasted through 1989. In 1990 the index value spiked, and the following year dropped to a low index value. 1992 was the lowest index of the chronology. There was a relatively steady increase in indices until the maximum index value was attained in 1998. Following 1998 there was a drop in indices and the values were below 1 again by 2000, and stayed low until equaling nearly 1 in 2006.

The residual chronology for Stand O (Figure 1: 3c) was quite variable jumping rather freely between high and low indices. The chronology started with indices jumping between being greater than 1 and nearly equal to 1 on almost a yearly basis until 1985 at which time there was a drop to a low index. From 1986 to 1989 the index values stayed nearly consistent with one another below 1. In 1990 the index value jumped to the highest of the chronology only to be followed by the chronology's lowest index in the following year. Starting in 1992 indices more or less increased in value, except for a slight dip in 1995, until reaching a local maximum in 1997. The index value for each year then decreased each year through 2000. In 2001 a high index existed, followed by the third lowest index for the chronology in 2002. The index values then gradually increased each year between 2003 and 2006 until having a value of nearly 1 in 2006.

4.1.2 Long Growth Chronologies

The longer (1931-2006) ARSTAN chronology for Stand O (Figure 2: b) was characterized by a nearly sinusoidal curve centered on an index value of 1, completing just over one cycle between 1931 and 2006. There was a period of high indices from 1953 to 1958, which were immediately preceded by a low index year. A period of particularly low indices lasted from 1965 through 1979, with low indices persisting until 1984. The lowest index of the chronology occurred in 1968. Indices bounced between low and high, generally becoming higher until 2006 when the maximum index of the chronology occurred.

The residual chronology for Stand O (Figure 2: c) for the years 1931 through 2006 was highly noisy, as would be expected with the removal of long-term trends. The indices bounce between high and low until 1970 when they stay low for a period of approximately ten years. After 1980 the index values return to bouncing between local maxima and minima until 2006 whereupon the chronology ends.

4.2 Site Comparison of Recent Growth Histories

4.2.1 Precipitation-Growth Correlations

Each stand showed a slightly different correlation with the unmodified total monthly precipitation data (Table 2). Stand O showed the strongest significant correlation value with the PRIMET precipitation data, with a correlation value of 0.520 for October of the current year, and 0.428 for June of the current year. Data from Stand M showed significant correlations with June of the current year with a value of 0.394, and October of the current year, 0.311. Stand Y, showed significant correlations with February of the current year, and both November and October of the previous year, with values of -0.489, -0.453, and -0.355 respectively.

4.2.2 Modified Precipitation-Growth Correlations

Significant correlations (>95% confidence level) were found in each of the three study areas (Table 3). Significant correlations within Stand O between the ARSTAN chronology and monthly precipitation, as determined by DendroClim2002, occurred in February, June, and October of the current year with correlation coefficients of 0.355, 0.386, and 0.520, respectively. Within Stand M significant correlation coefficients exist with precipitation in June and October of the current year with values of 0.403 and 0.311 respectively. The significant correlation between precipitation and annual ring-width growth in Stand Y is for February of the current year with a value of -0.451.

4.3 Long Growth History from an Old-Growth Stand

4.3.1 Precipitation-Growth Correlations

When correlated with the ARSTAN chronology, the only significant correlation (>95% confidence level) that emerged over the entire time series was with June precipitation of the previous year, with a correlation coefficient of 0.232 (Table 4). When Stand O was correlated with the Cascadia, Oregon precipitation data over the time period of 1980-2005 significant correlations emerged with precipitation for May of the current year and October of the current year, with coefficients of correlation being 0.408 and 0.492, respectively.

When employing the residual chronology and Cascadia, Oregon precipitation data, there were significant correlations over the entire time series (1931-2006) with June and April of the current year, as well as July of the previous year with correlation coefficients of 0.329, 0.262, and 0.229, respectively (Table 4). When the same data was restricted to the time period of 1980-2006, significant correlations emerged in June of the current year and November of the previous year with values of 0.358, and -0.364, respectively.

5. Discussion

5.1 Growth-Climate Correlation in Stands of Different Ages

5.1.1 Precipitation-Growth Correlations

The greatest significant correlation occurred between unmodified October precipitation and annual ring growth in Stand O (Figure 3). A high correlation value with October also occurred in Stand M. In contrast, the tree-ring growth of Stand Y showed no significant correlation with the same precipitation data. The same was noted for correlations with precipitation that fell during June of the current year. In addition, Stand Y was the only stand to show a significant correlation with precipitation that fell during February (Figure 3).

Lyon (1935) offered an explanation for the contrary correlations for the young stand. He suggested that the annual growth of rapidly growing trees is less affected than that of slow growing trees due to precipitation and temperature (Lyon 1935). Lyon (1935) suggested that young trees respond to an interaction of multiple environmental factors – stresses or releases – as opposed to a single factor. If this is true, then a study that can separate the complex interactions between the many limiting factors on vegetative growth, and its relation to tree-ring width would be necessary to be able to explain what exactly is affecting a young Douglas-fir tree’s annual ring-width growth.

The negative correlations that emerged between precipitation and Stand Y's chronology suggest that young trees grow better in years following a dry winter. A potential explanation for this is that with high precipitation, high nutrient leaching can occur. Particularly in newly formed soils and soils with high leaching potential, this is a potential situation. New stands in particular could face this problem, as following a disturbance there could be little organic matter and inputs into the soil to start with, much less following a large precipitation event and subsequent leaching of nutrients.

It is likely not a coincidence that June and October precipitation are significantly correlated with annual ring growth at the older sites, as these months are at either end of the growing season for the study area. Likewise, June and October precipitation have the greatest variability in precipitation of the months within the growing season for this area, which may be an influential factor. In addition, since summers are often droughty throughout the study area, provided that the Douglas-fir trees can use the precipitation shortly after it comes into contact with the ground, it is logical that October precipitation is correlated with ring-growth. Studies in other parts of the country, such as the one conducted in western Florida by Lodewick (1939), found that precipitation in the latter portion of the growing season was one of the primary influences on late wood formation. Late wood is not consistently extremely narrow in comparison to the early wood laid annually in these core samples, suggesting that perhaps this precipitation late in the growing season is vital to annual ring growth in our study sites as well. Due to rooting systems often occurring in the organic layer of the soil, it is not out of the question that late growing season precipitation is available to the tree for uptake. To determine the true necessity of late growing season precipitation, measurements of both the early wood and late wood for each year ought to be measured and compared in order to strongly support or refute this vitality and usability of the precipitation. Alternatively, monitoring of radial growth throughout the year could also give insight into the timing of growth in relation to precipitation.

Studies undertaken by others in British Columbia and the Pacific Northwest have come to similar conclusions as to the relation between precipitation and ring-widths. Early studies in Washington State by Hansen (1941) showed that correlations between precipitation for March through August and Douglas-fir ring growth occurred in roughly two-thirds of the years of his study. Studies carried out in British Columbia have come to similar conclusions in that precipitation has been positively correlated with Douglas-fir annual ring growth. Zhang (2004) found that ring-widths were positively correlated with May and July precipitation of the current year, with roughly 34% of variance in Douglas-fir ring growth attributed to climate variables (both temperature and precipitation). In the same vein, Watson and Luckman (2002) found that for Douglas-fir in the same area the range of correlation coefficients was 0.34-0.73 for annual precipitation. These annual precipitation totals were calculated from either the prior June to current May or prior July to current June (Watson & Luckman 2002).

5.1.2 Modified Precipitation-Growth Correlations

Due to the limited extent of the modifications made to the monthly precipitation data via the alteration of outliers, significant correlation values did not improve dramatically across the stands and even decreased correlation coefficients in several instances. October precipitation correlations to ring-width across all three stands did not change due to the lack of outliers existing within the month's data. However, for modified precipitation data in the month of June, the correlation with the ARSTAN chronology of Stand M increased by a small amount – approximately 0.009. This was a unique change in that the correlation for the same data with ring-widths in Stand O decreased by a greater amount – approximately 0.042. Likewise, there were mixed results for modified precipitation data for the month of February and the ring-widths of Stand Y and Stand O. The correlation coefficient decreased in negative correlation by approximately 0.04, while in the correlation between February precipitation and Stand O's ring-widths became significant where it was not with the unmodified data.

The inconsistency in response to modification in these results suggests that modification in this way did not uniformly remove the effects of severe precipitation events. To achieve this, identifying outliers on a daily – as opposed to monthly – basis could be beneficial so as to potentially identify days, weeks, or sets of weeks as particularly dry or wet anomalous events.

5.2 Long Growth History from an Old-Growth Stand

The analysis of a longer time series (1931-2006) of Stand O showed that significant correlations nearly disappeared between precipitation and the ARSTAN chronology. The only significant correlation that emerged was with the precipitation which fell during June of the previous year (Figure 4). There is little literature to suggest that this moisture would or would not be available to trees during their next growing season. However, due to the sometimes severe summer droughts that occur, it seems unlikely that this moisture would go unused by the trees and still be available a year later. Nevertheless, a lag in another form, such as a physiological lag, could be occurring. One such that there is a lag between water and carbon uptake, sugar creation, and resulting tree-ring growth fifty meters below where photosynthesis is occurring in the crown of the tree. There is little literature to support or refute the existence of such a physiological lag.

When the residual chronology was used as an input rather than the ARSTAN chronology entirely different significant correlations emerged. Precipitation totals in April and June of the current year, and July of the previous year resulted in significant correlations. The significance of precipitation from July of the previous year is called into question based on the same reasoning as significance with June precipitation of the previous year. The values of the correlations for April and June precipitation were greater than any correlation value resulting from comparison to the ARSTAN chronology. This increased correlation coefficient when the residual chronology was employed means that the negative exponential curve which was fit to the data was not sufficient to remove all of the impacts of stand dynamics on tree-ring growth. The significance of precipitation in the month of April may be due to the fact that there is a minimum of an 80% chance in any given year that temperatures will be such that rain will be the predominant precipitation type, meaning near immediate availability of water for uptake by plants (Oregon Climate Service). It would still be necessary to show that precipitation is utilized during this month as the source of water for the trees, as opposed to stored ground water. Likewise, June is early enough in the year that drought is not often a significant factor in limiting plant growth during that month in the Pacific Northwest, particularly at these elevations. Therefore, studies regarding the ecophysiology of Douglas-firs are necessary in order to determine why June precipitation is significantly correlated with tree-ring growth.

6. Significance

The discrepancies between stands of different ages in terms of correlation with precipitation gives some insight as to the potential importance of specific ecological factors, in this case water availability. In particular, these data show that young stands do not appear to react to water availability following months of drought in the same manner as a mature or old-growth stand. Throughout the Pacific Northwest these responses to water availability are of particular interest due to the wide-ranging effects of climate change. The IPCC Report on Regional Impacts of Climate Change states that precipitation has been and will continue to increase across western Oregon and northward through western Canada (Ball et al. 1997). Our data suggest that this increase could have an effect on a stand of any age, depending upon the timing of precipitation increases. This has implications for both stand dynamics, and the production of commercial forest products.

This study identified a clear dichotomy between the response to precipitation of young stands versus mature and old-growth stands. As such, this conclusion can be extrapolated to all trees, when young, respond differently than when mature to precipitation availability. This has significant implications for the treatment of cores for climate reconstruction and drought reconstruction in particular. Specifically, our data suggests that tree-cores ought to be considered in two segments – a segment of young growth and a segment of mature through old-age – when reconstructing water availability.

In general, this study expands the base of knowledge regarding tree-ring and climate correlations, particularly in the western Oregon Cascade Range where relatively few studies have been carried out.

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Month	Number Modified
January	2
February	2
March	1
April	1
May	0
June	1
July	2
August	2
September	1
October	0
November	0
December	2
Total	14

Table 1: Number of monthly PRIMET precipitation values modified between 1980 and 2006 for the purpose of removing outliers.

Stand	Month	Correlation
Stand Y	October-1	-0.355
Stand Y	November-1	-0.453
Stand Y	February	-0.489
Stand M	June	0.394
Stand M	October	0.311
Stand O	June	0.428
Stand O	October	0.520

Table 2: Significant correlations by month between the ARSTAN chronology for each stand and unmodified PRIMET precipitation for 1980-2006, as determined by DendroClim2002. "-1" following a month designates a month of the previous calendar year.

Stand	Month	Correlation	Change in Correlation
Stand Y	February	-0.451	-
Stand M	June	0.403	+
Stand M	October	0.311	0
Stand O	February	0.355	new
Stand O	June	0.386	-
Stand O	October	0.520	0

Table 3: Significant correlations by month between the ARSTAN chronology for each stand and modified PRIMET precipitation, as determined by DendroClim2002. 'Change in Correlation' is in comparison to correlations previously made with unmodified PRIMET precipitation data with the same chronologies.

Month	Time Series	ARSTAN Correlation	Residual Correlation
June-1	1932-2006	0.232	--
July-1	1932-2006	--	0.229
April	1932-2006	--	0.262
June	1932-2006	--	0.329

Table 4: Significant correlations between precipitation data from Cascadia, Oregon and Stand O chronologies for the time series 1932-2006, as determined by DendroClim2002. "-1" following a month designates a month of the previous calendar year. "--" designates that no significant correlation was found between precipitation and a particular chronology.

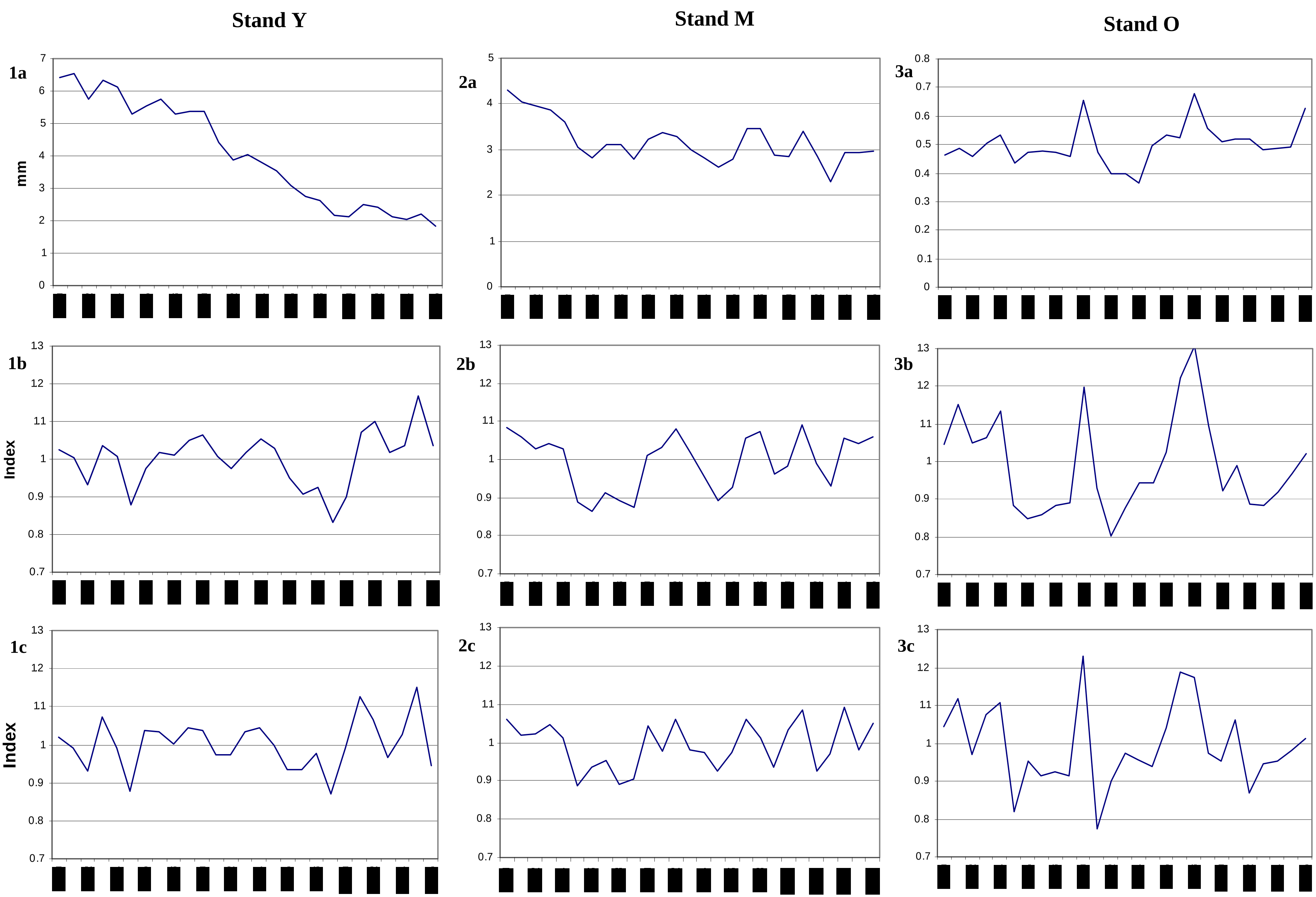

Figure 1: Raw mean ring-width in millimeters and chronologies as determined by ARSTAN for each stand. 1: Stand Y a) raw ring-widths; b) ARSTAN chronology; c) residual chronology. 2: Stand M a) raw mean ring-widths; b) ARSTAN chronology; c) residual chronology. 3: Stand O a) raw mean ring-widths; b) ARSTAN chronology; c) residual chronology.

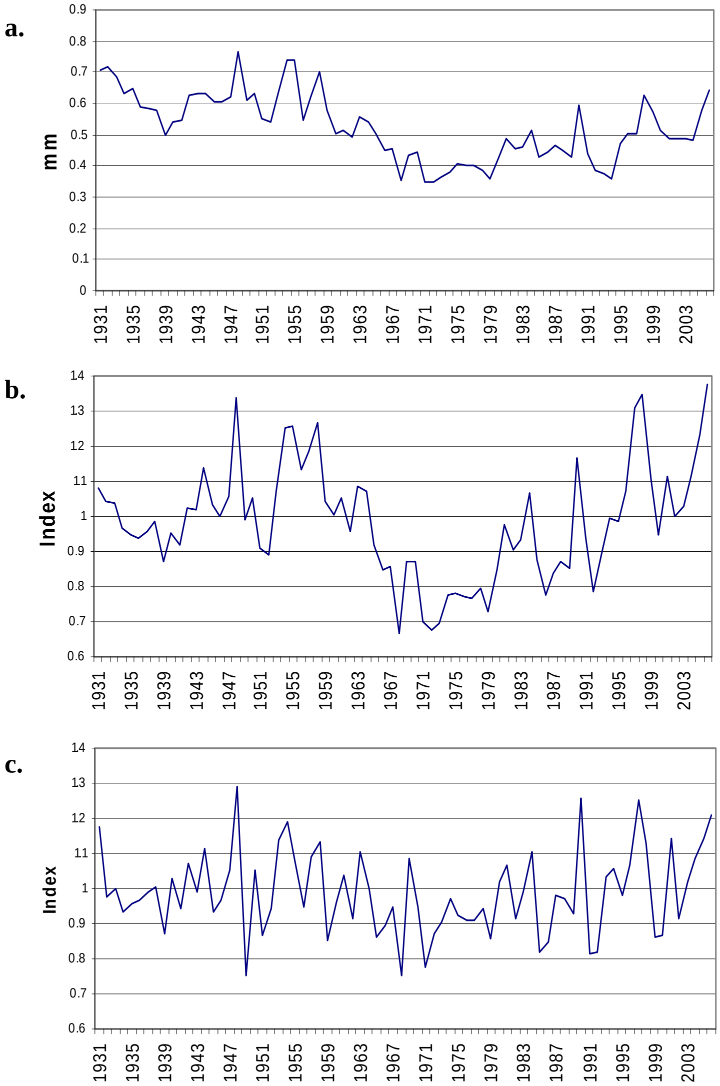

Figure 2: Stand O (1931-2006) mean raw ring-width in millimeters and chronologies determined by ARSTAN. a) raw mean ring-width in millimeters by year; b) ARSTAN chronology; c) residual chronology.

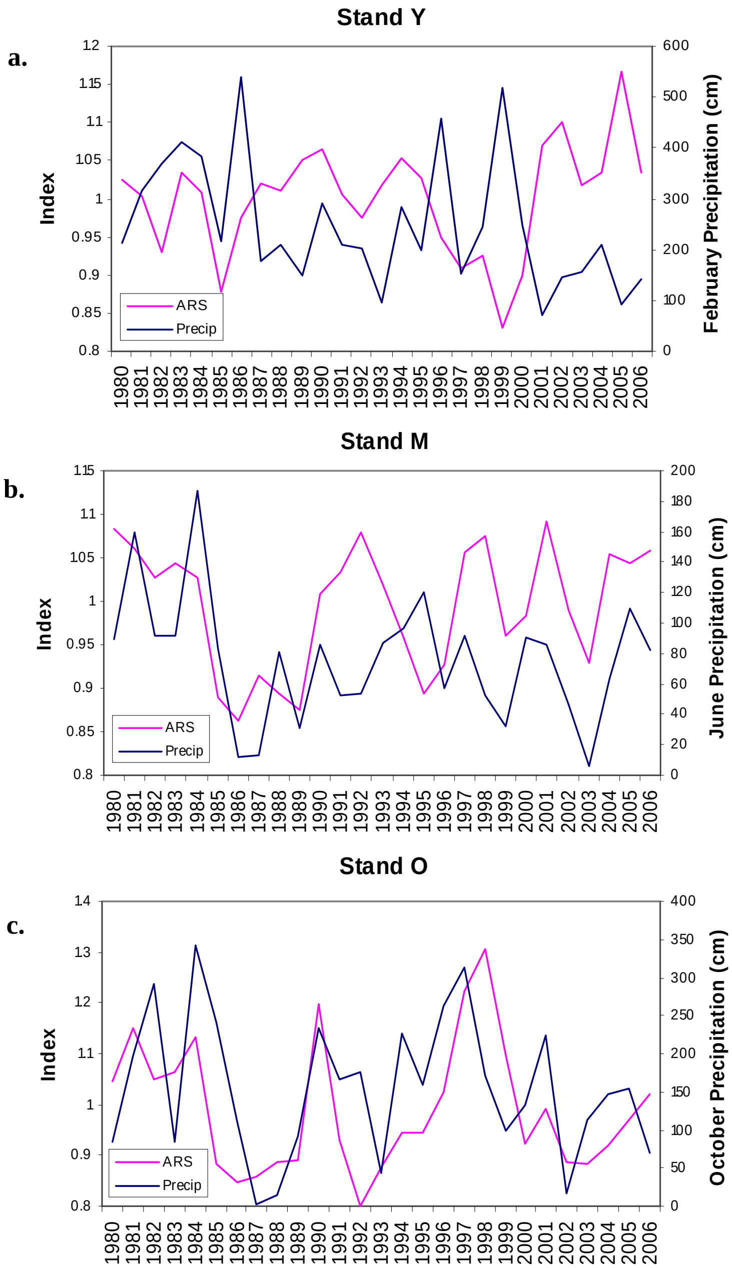

Figure 3: The strongest significant correlation for each stand between the respective ARSTAN chronology (ARS) and total precipitation (cm) in a month. a) Stand Y: correlation between February precipitation and ARSTAN chronology; b) Stand M: correlation between June precipitation and ARSTAN chronology; c) Stand O: correlation between October precipitation and ARSTAN chronology.

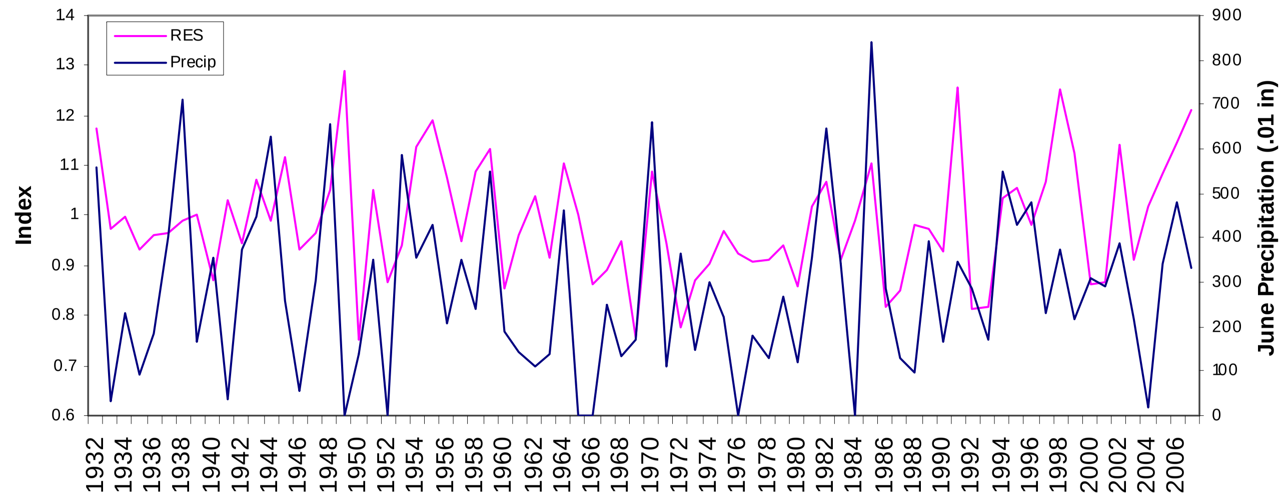

Figure 4: The strongest significant correlation for the long growth history (1931-2006) of Stand O. This correlation was between the residual chronology (RES) and June precipitation in hundredths of an inch.