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REVIEW OF DENDROCLIMATOLOGY LITERATURE RELEVANT TO WESTERN OREGON

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Danielle Robbins
Department of Forest Science
Oregon State University
Corvallis, OR 97331
oregonforestfire@yahoo.com

Introduction

Climate change research is important in the context of today's concern about global warming and the implications that holds. Climate variability drives changes in vegetation and disturbances such as fire, insect outbreaks, drought, and flooding. In the Pacific Northwest, tree rings have been used to reconstruct numerous climate variables back in time for hundreds of years. Climate variables include annual and seasonal precipitation, temperature, and snow pack; as well as longer-term variations such as El Nino-Southern Oscillation (ENSO) and Pacific Decadal Oscillation (PDO). However, there is a paucity of reconstructed climate for the region west of the crest of the Cascade Range of Oregon and Washington.

As public lands managers and policy makers grapple with decisions regarding management of natural resources, understanding how climate naturally fluctuates over time is a vital component of that decision process. Swetnam and Betancourt (1998) point out that before variation in ecosystem components are attributed to other causes, the regional climate signal must be taken into account. Furthermore, accounting for climate variation at the century to millennia scale is particularly relevant when assessing changes in keystone ecological processes, such as fire (Swetnam and Betancourt 1998; Elias 2003).

The objective of this literature review is to compile and synthesize dendroclimatological studies in the Pacific Northwest for the purpose of creating a frame of reference for future dendroclimatology work in western Oregon. Climate reconstructions for parts of the Southwest USare also included in this review since there have been more reconstructions for that region and because the effects of large scale climate variation, such as ENSO, are generally opposite that of the Pacific Northwest (PNW), thus PNW and SW reconstructions are often compared. This literature review is supported in part by the Andrews Forest Long-Term Ecological Research program.

Climate Overview

Fluctuating ocean temperatures and atmospheric conditions over the tropical Pacific Ocean drive large-scale air temperature and precipitation patterns over much of the continental United States. The eastern half of the equatorial Pacific Ocean off the western coast of Central and South America is normally the coldest part of the ocean, but experiences considerable variation during the course of each year. Easterly winds blowing over the Pacific cause waves in the thermocline separating warm upper-ocean water from cold deep-ocean water, which drives upwelling of cold water. Under normal conditions, the thermocline is shallow in the eastern Pacific, allowing cold water to surface. This process keeps sea surface temperatures warm in the western Pacific.

El Nino

In response to a decrease in low-level easterly winds, increases of sea level (10s of cm) and the depth of the thermocline (10s of meters) occur in the eastern equatorial Pacific. Typical upwelling of cold water in the east ceases, producing warmer subsurface water temperatures. In addition, air pressure becomes abnormally high in the western Pacific and low in the eastern Pacific; this is known as the negative phase of the Southern Oscillation.

El Nino occurs roughly every two to seven years and lasts for about 12 to 18 months. During El Nino events, several changes occur in the wintertime atmospheric flow, including the southward shift of the storm track (Pacific jet stream) from the northern to the southern US and a low pressure ridge off of the coast of western Canada that shifts the cold, polar jet stream eastward. This results in warmer and drier conditions in the PNW and cooler, wetter conditions in the southwest U.S. La Nina, the “sister opposite” of El Nino, produces cooler, wetter conditions in the PNW, while in the southwestern U.S. La Nina is associated with drought.

Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) is a shift in sea surface temperatures (similar to ENSO), however, the PDO shift is more gradual, subtle, and protracted (1-2°C over 15-30 years) and occurs over a much larger area. The negative or cool phase of the PDO is associated with cool, wet conditions in the PNW and occurred twice in the last century (1890-1924 and 1947-1976). The positive or warm phase is associated with warm, dry conditions and occurred between 1925 and 1946 and from 1976 to the mid 1990s. Currently, there is debate concerning the shift to a cool phase around 1995, which has significant implications for the southwestern U.S., as the climate there during the cool phase is associated with drought.

Dendrochronology: State of the Art

Background

Dendrochronology has been used for decades for accurately dating human structures; determining past climate variables such as drought; and interpreting forest history, including fire history (Fritts 1976; Fritts and Swetnam 1989; Bradley 1999; Hughes 2002). The foundation of dendrochronology is “crossdating”, which is matching similar tree ring width patterns between tree samples. Because trees may vary in growth rate in response to exogenous factors such as precipitation, length of growing season, and within-stand competition, tree rings are good recorders of past conditions and groups of trees (stands) tend to react similarly to these forces. For example, ponderosa pine on the east side of the Cascade Range grows in an area of low annual precipitation and is, therefore, sensitive to fluctuations in precipitation. A year of higher-than-average rainfall would be represented by wider-than-average ring width. Because precipitation varies in broad, synchronous patterns, many trees (not all) from a stand or from some much larger area (up to ~1000-2000 km^2) (cite) may have a similar wide ring for that year.

Dendroclimatology is the use of dendrochronology to assess past climatic variables. Physiological processes of trees, including photosynthesis, respiration, assimilation, and cambial activity, react to climatic regimes. Tree-ring width is typically used in dendroclimatology analyses, although maximum latewood density (which is a measure of the highest density in the latewood cells formed at the end of the growing season) is also used, particularly for tree species with a more complacent response to climate change. For instance, in the northern boreal forests, some conifer species may not exhibit sufficient annual tree ring width variation for modeling climate change, but low latewood density values have been associated with cool growing seasons (Wiles et al. 1996).

Individual trees at the limit of the ecological range of the species commonly respond to a single climatic factor, whereas the response of trees in the center of their range may be more complicated. In the San Francisco Mountains of Arizona, for example, trees from "forest border" sites (at the edge of the forest) tended to have higher year-to-year ring width variability than trees from the forest interior (Fritts et al. 1965).

Strengths and Weaknesses

According to Hughes (2002), there are several strengths and weaknesses in the art of dendroclimatology. The most important strength is the ability to date tree rings to a calendar year with a high degree of confidence. The high confidence level of dating permits climate reconstructions to be calibrated and tested with modern, temporally short instrumental records to provide a basis for extending the climate record. Also, unlike other natural climate archives, such as lake deposits and ice cores, the temporal scale can range from annual to decadal to multi-century. Large geographic patterns of common annual tree-ring variation make it possible to reconstruct climate over very large areas, including the continental level. These large scale reconstructions can be used to evaluate occurrence of El Nino-Southern Oscillation (ENSO), which has been shown to influence fire, insect outbreaks, and episodic tree mortality (Swetnam and Betancourt 1998); PDO, which is a 15-30 year flux in pressure gradients over the PNW (Pohl et al 2002); and other types and scales of climate variation.

The most important weakness of dendroclimatology is that climate reconstructions typically capture only 40 to 50% of the variance of the factor being considered, based on comparison with instrumental records. Another weakness is that tree rings may not reconstruct the desired climatic variable since few trees are responding to a single monthly or seasonal variable and trees do not respond equally throughout a season. For example, Biondi (2000) found that Douglas-fir in the PNW responds to both prior-year summer temperature and to current year spring precipitation; however, Zhang et al. (1999) reported that Douglas-fir in central British Columbia responds to current-year summer temperature and current spring precipitation.

A necessary part of constructing a chronology is detrending of the data as part of the standardization process. This removes variations in tree ring width due to non-climate related variations, such as tree age and within-stand competition. However, detrending also removes climate variations at the centennial and longer time scales. Also, climate fluctuations that occur on time scales longer than the lifetime of the trees cannot be reconstructed, thus we are limited by the longevity of tree species and by tree senescence.

Climate is reconstructed under the assumption that the relation of tree growth and climate that operated in the past continues today. In dendroclimatology, checks of past climate conditions using data and evidence from other sources support the legitimacy of using this assumption in climate reconstructions (Fritts 1976). However, some species and some parts of the world are not conducive to constructing chronologies. Certain tree species do not respond readily to climate fluctuations; typically individuals not at the limit of their range or that are in protected areas of abundant resources, such as trees located near stable water sources. Trees in climates that do not have distinct seasons, commonly produce several rings per year (Fritts 1976), making it difficult to date annual rings accurately.

Previous Dendroclimatological Studies

For the annotated part of this review we emphasize dendrochronological studies that specifically reconstructed climate history or that compared tree-ring chronologies with contemporary climatic data. Annotations are listed by geographic region (continental US, PNW including Canada, and Southwestern US and Mexico). In addition, since many dendroclimatological studies have focused on the relation between historic climate and fire or have inferred climate from historic fire patterns, we also list, but do not annotate, studies that inferred climate from fire. Also listed are additional dendroclimatological studies that are not annotated.

<u>Continental US</u>

Cook et al (1999): reconstructed drought using the Palmer Drought Severity Index (PDSI). The authors used a grid system (2° lat. X 3° long.) of climate stations with historical climate records, which totaled 154 points. All climate records covered the common period of 1700 to 1978. Four hundred twenty five tree-ring chronologies were used for PDSI climate reconstructions. The chronologies were highly patchy due to the uneven distribution of forested land and to the distribution of tree species that are usable for dendrochronology work. The annual PDSI maps are available at: http://www.ngdc.noaa.gov/paleao/pdsiyear.html.

<u>Pacific Northwest (including Canada)</u>

Knapp et al. (2002): Identified extreme climatic pointer years (CPYs), which are severe, single-year droughts, using western juniper (*Juniperus occidentalis*) from the interior PNW (including Oregon, Idaho, Nevada, and northern California) for the period 1500-1998. CPYs were concentrated in the 16th and early 17th centuries and in the early 20th century. Winter and spring precipitation, which is the climatic factor that most influences western juniper growth, varied greatly over the study area, thus climatic boundaries were developed that reflect this precipitation variation as well as the CPYs.

Pohl et al. (2002): Reconstructed drought for central Oregon (Newberry Volcanic National Monument) using a 545-year ponderosa pine tree-ring chronology. The relation between drought (PDSI), ENSO (SOI), and PDO was determined, and ponderosa pine and western juniper were evaluated for suitability in constructing climate proxies. The tree-ring chronology had a very weak negative correlation with SOI (1900-1999) and a weak but significant correlation with PDO (lagged at 6 years). Reconstructed PDSI (1455-2000) explained 35% of the variance of observed (instrumental) PDSI; tree growth was most strongly related to PDSI, since soil moisture is included, which is a prominent factor for trees growing on old lava flows. The most pronounced drought occurred in the decades of 1480, 1630, 1700, and 1930.

Watson and Luckman (2002): Compared tree-ring growth with precipitation, temperature, and PSDI using low-elevation Douglas-fir (*Pseudotsuga menziesii*) and ponderosa pine (*Pinus ponderosa*) from the southern Canadian Cordillera (located in both B.C. and Alberta). Growth rates were most highly correlated with water availability during the growing season, although the two species differed slightly. Douglas-fir growth was correlated more strongly with precipitation of the previous year and early summer; ponderosa pine was more correlated with current year and late summer (July) precipitation. They also determined climatic correlations with early and latewood growth. Earlywood growth was most correlated with precipitation from the previous summer (July and August) and latewood growth was more strongly related to current summer precipitation (June and July).

Gedalof and Smith (2001): Reconstructed climate for the period 1600 to 2000 using subalpine mountain hemlock (*Tsuga mertensiana*) at sites extending from northern California to southern Alaska. Tree growth was most limited by summer precipitation throughout the region. Warm spring and summer temperatures enhanced growth for the current year, but inhibited growth for the following year. They found that Alaskan chronologies were distinctly different from all other chronologies along the Alaska-to-California transect. However, common intervals of above-average growth included 1635, 1780, 1805, and 1830-1840. Below average radial growth occurred in 1620, 1730, 1745, 1815, 1850, and 1895. An interval of reduced growth south of Alaska occurred at approximately 1955, which corresponds to an extreme negative PDO index.

Biondi (2000): Compared a Douglas-fir tree ring chronology (1895 to 1995) with monthly precipitation, temperature, and PDSI for the Salmon River Valley of Idaho. Tree growth had a negative response to July temperature and a positive response to May precipitation. This combination of responses indicates that Douglas-fir growth at this site is driven by moisture stress in the growing season.

Laroque and Smith (1999): Reconstructed precipitation and temperature using yellow-cedar (*Chamaecyparis nootkatensis*) from montane sites on Vancouver Island, B.C.. The authors correlated radial growth and climatic factors for the period 1800 to 1994. They found that six variables of temperature and precipitation accounted for 61% of the variance in annual ring width, which indicates the usefulness of yellow cedar for dendroclimatological studies. Reduced radial growth was most pronounced during the decades of the 1800s, 1840s, 1860s, 1920s, 1950s, and 1970s. Periods of higher growth included the mid-1820s, 1880s, 1910s, 1940s, and 1960s. Positive growth rate was associated with 1) warm July temperature; and 2) February precipitation. Negative growth rate was associated with 1) August temperature during the current year; 2) August temperature during the previous year; 3) higher than average precipitation in June; and 4) higher than average precipitation in October of the preceding year.

Zhang et al. (1999): Reconstructed precipitation and temperature (1650-1992) anomalies using Douglas-fir, subalpine fir, and interior [Engelman] spruce (*Picea engalmannii*) in central

BC, Canada. Douglas-fir was the most climate-sensitive species and radial growth was most related to spring precipitation and early summer temperature. Growth of subalpine fir and spruce was negatively affected by high summer temperatures. Moist springs and moderate summers prevailed from the late 1750s-1800s. From the late 1860s to early 1870s, dry springs, hot summers, and cold late falls dominated.

Perkins and Swetnam (1996): Established the response of whitebark pine (*Pinus albicaulis*) growth to annual temperature and precipitation for the Sawtooth-Salmon River region of central Idaho. Above average tree ring growth was positively correlated with winter and spring precipitation and negatively related with May temperature, which may reflect an influence of seasonal snowpack.

Wiles et al. (1996): Coastal tree ring and maximum latewood density chronologies from Douglas-fir, mountain hemlock, Sitka spruce (*Picea sitchensis*), and white spruce (*Picea glauca*) were used to reconstructe temperature for the Gulf of Alaska (GOA), Washington, and Vancouver Island (1750-1983). The GOA ring width and density chronologies had positive correlations with the growing season (March-September); density chronologies also had a negative relationship with previous July-November temperatures. Washingtondensity chronologies had a positive correlation with temperature from April to September. Temperatures for the GOA were cool from 1800-1815, 1840-1860, and the late 1800s; warm temperatures occurred during the decades centered on 1825, 1870, and 1920. For the Washington and Vancouver Island region, temperatures were warm for a 20-year period in the early 1800s and for the summers of the 1830s, 1850s, and 1870s.

Graumlich (1987): Reconstructed precipitation (1675-1975) for Washington, Oregon, and northern California using tree-ring chronologies from Douglas-fir, ponderosa pine, jeffrey pine (*Pinus jeffreyi*), sugar pine (*Pinus lambertiana*), whitebark pine, subalpine larch (*Larix lyallii*), and western larch (*Larix occidentalis*). Similar precipitation patterns over the past several centuries were identified for southern OR and northern CA and for northern OR and WA. For example, precipitation in the early 1800s was above average in northern OR and WA, but below average for southern OR and northern CA; the reverse was true for the latter half of the century. The 20 most severe drought years for each of three climatic zones were determined (p. 27); however, some single-year droughts affected all of the PNW (1717, 1721, 1739, 1839, 1899, 1929, and 1973).

Graumlich and Brubaker (1986): Reconstructed temperature (1590-1979) for the Washington Cascades using mountain hemlock and subalpine larch. Radial growth was positively correlated with summer temperature (July-Sept.) and negatively with spring (March) snow depth (when depth is at or below normal). Mean annual temperature reconstructions showed that temperature before approximately 1900 was 1°C lower than that observed for the 20th century (with the exception of the period 1650-1690). Cooler than average periods occurred from 1600-1650, 1700-1760, and 1860-1900.

Southwestern U.S. and Mexico

Diaz et al. (2001): Reconstructed precipitation (1862-1996) using laguna pine (*Pinus cembroides* var. *lagunae* or *Pinus lagunae*), which is endemic to the Sierra de La Laguna mountain range at the tip of Baja California Sur, Mexico. Extremely dry and wet years in the precipitation reconstruction were compared with ENSO events. They found a long drought period from 1939 to 1958; and the "wettest" year was 1983, one of the strongest El Nino events of the 20th century. Other extremely wet years were 1905, 1912, and 1919. Winter precipitation has the most effect on growth in the region due to soil moisture recharge, but summer precipitation is not as important since most of the precipitation results in runoff. ENSO influences winter precipitation.

Stahle et al. (1998): Reconstructed winter SOI (ENSO) for the period 1706-1977, using several tree-ring chronologies (both earlywood and total width) from subtropical North America (NM, Iowa, CO, OK, UT, AR, and Mexico) and Java, Indonesia. Tree species included Douglas-fir, ponderosa pine, post oak (*Quercus stellata*), pinyon pine (*Pinus edulis*), and teak (*Tectona grandis*) from Java. They found an increase in the frequency of both warm and cold winter SOI extremes after 1870.

Biondi et al. (1997): Reconstructed precipitation and temperature (1827-1994) using torrey pine (*Pinus torreyana*). Torrey pine grows in a limited range on Santa Rosa Island and the California coast between San Diego and Del Mar. Tree growth was related to previous winter and current spring precipitation (November – April); temperature was not related to tree growth.

Grissino-Mayer et al. (1997): Reconstructed precipitation (136 BC-1992) using long-lived trees and remnant logs of Douglas-fir and ponderosa pine growing on a lava flow in El Malpais National Monument, New Mexico. Climate was dominated by seven alternating, long-term periods of above average (810-257, 521-660, 1024-1398, and 1791-1992) and below average precipitation (258-520, 661-1023, and 1399-1790). These longer periods were also interspersed with short-term above and below average precipitation periods.

Graumlich (1993): Reconstructed summer temperature and winter precipitation back to the year 800, using foxtail pine (*Pinus balfouriana*) and western juniper in the southern Sierra Nevada, California. Tree-sample collection sites differed by elevation, topographic position, and substrate to emphasize different variables important to tree growth (temperature or precipitation) in order to compare tree growth to temperature and precipitation reconstructions. She found that summer temperature fluctuated on much longer time-scales (centennial and longer) than does precipitation (decadal). Warm temperature dominated ca. 1100 to 1375 (Medieval Warm Period), and cooler temperatures from ca. 1450 to 1850 (Little Ice Age).

Stahle and Cleaveland (1993): Reconstructed SOI (1699-1971) using many previous tree-ring studies throughout northern Mexico and the Great Plains of the southern US. Species included Douglas-fir, ponderosa pine, Jeffrey pine, and white fir. This work focused largely on the quality of the "signal" for the different reconstructions with respect to SOI (rather than calendar year SOI signals).

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