Final Report

Title: **Combining Modern and Paleo-Climate Data to Enhance Drought Prediction and Response**

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Problem and Research Objectives:

The State of Wyoming spent more time during the 20th Century under severe drought conditions (Palmer Drought Severity Index <-3) than any other state except Colorado (McKee et al. 1993; NOAA 1990). In fact, half of Wyoming's major river basins experienced severe drought conditions for more than 15% of the time from 1895-1995 (WGA 1996; NDMC 2000), accounting for millions of dollars in damage to crops, livestock, and wildlife along with diminished tourism and wildfires (WGA 1996).

A clear need exists for assessing potential drought impacts, developing contingency plans, and identifying inception of meteorological droughts. However, the drought record of the past 100-130 years is inadequate for implementation of these tasks. A more complete and realistic appraisal of Wyoming drought requires assessment over a much longer period, spanning several centuries. Sole dependence on the past century's record in assessing drought susceptibility and impact is analogous to a physician's relying only on the past five years of a patient's medical history, which may not include earlier events diagnostic of susceptibility to disease, allergy, or infection. In the case of drought, symptoms of susceptibility to severe and prolonged events, possibly far worse than those experienced during the past century, can only be observed by examining the records of previous centuries. Those records are available in tree-ring archives for many regions of Wyoming. Tree-rings are an excellent source of drought proxy data because of their long duration (centuries to millennia) and high (at least annual) temporal resolution (Fritts 1976). Furthermore, tree-rings have been used with great success in documenting droughts throughout North America (Cook et al. 1995) and to reconstruct the relationship between droughts and circulation indices (Stahle et al. 1998). By developing a network of tree-ring records from western Wyoming, we are providing a detailed reconstruction of drought events spanning the last 500 to 1000 years that can be used to enhance our understanding of extreme climate events in this state and the Rocky Mountain West as a whole.

Methodology:

This project centered on the development of a network of tree-ring sites selected to provide 600-1,000+ year reconstructions of regional droughts in western Wyoming, and the use of those records to improve methods of drought prediction.

Study Area: This study focuses on western Wyoming, specifically the Clark's Fork, Shoshone, Bighorn, Wind, and Green River drainages. Tree-ring sites along the edges of the Bighorn Basin and in the Flaming Gorge area of SW Wyoming and NE Utah form the core of our network.

Field Techniques: Tree-rings are useful for drought reconstructions when water availability becomes critically limiting and persists for long enough that the growth of many trees over a wide area is affected (Fritts 1976). At lower elevations, growth is most often limited by precipitation. Therefore, we have selected a network of sites at lower tree line for drought reconstructions. Our work shows that limber pine (*Pinus flexilis*), Douglas-fir (*Psuedotsuga menziesii*), ponderosa pine (*Pinus ponderosa*) and pinyon pine (*Pinus edulis*) are the most appropriate species for drought reconstructions in the study region. These species are found on dry sites throughout the area and reach sufficient age to produce 600-1,000+ year climate reconstructions. Over the course of this project we sampled over 600 trees, including dead snags and sub-fossil wood, at 13 sites throughout the study area.

Dating and Measurement of Cores: In the laboratory, we dried, mounted, and progressively sanded all cores to at least 400 grit (Cook and Kairiukstis 1990, Grissino-Meyer 1996), and assigned exact dates to each ring using standard cross-dating methods (Stokes and Smiley 1968, Swetnam et al. 1985). We then measured all rings from the dated series to the nearest 0.001 mm using a computer-based optical measuring device.

Reconstructing Droughts from Tree Growth: We used correlation analysis to compare modern meteorological records with tree-ring widths produced during the same time period (Fritts 1976). Monthly or seasonal climate variables with the highest correlation coefficients are then chosen for reconstruction. Response functions, a type of statistical equation describing the relationship between climate and growth, were then developed (Fritts 1991). After using subsets of the data to verify the climate/growth relationship, a new transfer function is developed which provides reconstructed climate values by substituting ring widths in the equation.

Investigating the relationship between drought and large-scale circulation patterns: We used methods developed by Hirschboeck et al. (1996), Woodhouse (1997), and Cayan et al. (1999) to determine the relationship between circulation indices (CI) and drought in western Wyoming. Using more extensive networks of tree ring sites obtained from the International Tree Ring Data Bank (www.ngdc.noaa.gov/paleo/treering.html), we repeated these analyses for the entire central and southern Rocky Mountain regions. Briefly, we compared the occurrence of both modern and paleo droughts with independent CI records using a combination of regression-based and event-based techniques. Using the regression-based approach, we looked for correlations between droughts recorded in the instrumental record and CIs for the same time period. We then used event-based analysis, a technique that looks for coincidence between unusual climatic events, to determine if extreme CI values correspond with regional droughts. Since the instrumental record has several important limitations, we repeat these analyses using data from our tree-ring sites.

Principal Findings and Significance:

During the course of this project, we completed sampling and analysis of tree-ring sites throughout the study area. In total, we have sampled trees at 13 sites. Seven sites are in the Bighorn Basin portion of the study area, making this one of the densest climate reconstruction networks in the Rocky Mountain region. To date, key findings from the project include:

1. Drought events in our long-term tree ring records are often longer and more severe than any droughts observed in the instrumental record of the past 120 years. Therefore, modern droughts do not represent the scope of events we should expect and plan for.
2. Statistical analyses of our long-term drought records show that dry events often occur at more-or-less regular intervals. In particular, droughts often return at both 30 and 50-year cycles throughout much of the study area. However, these oscillations are not stable through the entire proxy record, and should not be over-emphasized in predictive models of drought.
3. Drought conditions in western Wyoming are often highly persistent. In the Southwestern U.S., 2-3 years of drought are often followed by several years of normal to wet conditions. In Wyoming, however, dry years are much more likely to be followed by additional dry years, with drought cycles often extending over 10 or more years. The 20th Century has been somewhat unusual in that this persistence has been dampened. A return to the high-persistence mode of the previous several centuries would lead to droughts of far greater duration than those experienced in recent decades.
4. Droughts in western Wyoming show a strong link to circulation patterns in the northern and tropical Pacific. However, the strength and sign of these correlations may vary over time. More specifically, the relationship between precipitation variability and ENSO (El Nino-Southern Oscillation) varies throughout western Wyoming and much of the central Rockies.
5. Circulation anomalies in the Gulf of Mexico and Northern Atlantic may lead to rare but severe and long-duration drought events that affect the entire Rocky Mountain Region from Montana to the Mexican Border. Evidence from western Wyoming and our expanded network of tree-ring sites in the Rocky Mountain Region also suggest that variations in Atlantic Basin sea surface temperatures can modulate the influence of Pacific phenomena (i.e. ENSO) on the climate of Western North America.

While the data derived from our study has already contributed to our understanding of drought in Wyoming and much of Western North America, this research will also play a key role in future work. Our tree-ring records are being used as input for models designed to study the frequency, duration and distribution of drought conditions throughout North America (Ed Cook, Lahmont Doherty Earth Observatory). Our tree-ring records for southwestern Wyoming and northeastern Utah will also play a key role in efforts to understand water resource issues in the Upper Colorado River Basin (Connie Woodhouse, NOAA).

Publications:

Gray, S.T., S.T. Jackson, and J.L. Betancourt, 2004. Tree-ring Based Reconstruction of Precipitation Variability for Northeastern Utah. J. of the American Water Resources Association (in press).

Gray, S.T., 2004. “Long-term perspectives on Wyoming drought: lessons from the tree-ring record.” Pp. 97-101, in J. Curtis and K. Grimes, eds. *Wyoming Climate Atlas*.

Gray, S.T., C.L. Fastie, S.T. Jackson, and J.L. Betancourt, 2004. Tree-Ring-Based Reconstruction of Precipitation in the Bighorn Basin, Wyoming, Journal of Climate, American Meteorological Society, Vol. 17, October, pgs 3855-3865.

Gray, S.T., L.J. Graumlich, J.L. Betancourt, and G.D. Pederson, 2004. A tree-ring based reconstruction of the Atlantic Multidecadal Oscillation since 1567 A.D. *Geophysical Research Letters,* 31:L12205, doi:10.1029/2004GL019932.

Gray, S. T., J. L. Betancourt, C. L. Fastie, and S. T. Jackson, 2003. Patterns and sources of multidecadal oscillations in drought-sensitive tree-ring records from the central and southern Rocky Mountains, *Geophys. Res. Lett.*, *30*(6), 1316, doi:10.1029/2002GL016154.

Gray, S.T. 2003. Long-term Climate Variability and its Implications for Ecosystems and Natural Resource Management in the Central Rocky Mountains. Ph.D. Dissertation, Botany, A&S College, University of Wyoming, Laramie, Wyoming.

Gray, S.T., S.T. Jackson, and J.L. Betancourt. 2002. Tree-ring based reconstructions of precipitation variability in northeastern Utah. *Proceedings of the 2003 Pacific Region Climate Workshop (PACLIM), Pacific Grove, California.* http://tenaya.ucsd.edu/~dettinge/PACLIM/Abstracts_PACLIM03.pdf

Gray, S.T., S.T. Jackson, and C.L. Fastie. 2001. Use of Paleoclimate Proxy Data to Enhance Drought Planning and Response. *Proceedings of the 2002 Pacific Region Climate Workshop (PACLIM), Pacific Grove, California.*
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Gray, S.T. C.L. Fastie, S.T. Jackson, J.L. Betancourt and K. Taylor. 2001. 1000 year drought records from tree-rings in the Bighorn Basin, Wyoming. *Proceedings of the 2001 Annual Meeting of the Ecological Society of America,* Madison, Wisconsin http://abstracts.allenpress.com/esa-cgi/document.cgi?YEAR=2001&ID=28695

Awards:

The paper, “Tree-ring based reconstructions of interannual to decadal-scale precipitation variability for northeastern Utah since 1226 A.D.”, authored by Stephen T. Gray, Stephen T. Jackson, and Julio L. Betancourt, published in 2004 in *Journal of the American Water Resources Association*, received the 2005 Boggess Award from the American Water Resources Association. The Boggess Award is given annually to honor the authors of the best paper published in the *Journal of the American Water Resources Association* in the previous year. This paper derived from a chapter in Steve Gray’s 2003 doctoral dissertation in the Botany Department at UW. His dissertation received the 2005 “Outstanding Dissertation Award” from the Graduate School.