# COVER SHEET FOR PROPOSAL TO THE NATIONAL SCIENCE FOUNDATION

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| PROGRAM ANNOUNCEMENT/SOLICITATION NO./CLOSING DATE/if not in response to a program announcement/solicitation enter NSF 04-23<br>**NSF 01-113** | FOR NSF USE ONLY<br>NSF PROPOSAL NUMBER |
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TITLE OF PROPOSED PROJECT **Doctoral Dissertation Research: Drought sensitivity of limber pine in the central Rocky Mountains determined from C isotopes and ring widths**

| REQUESTED AMOUNT | PROPOSED DURATION (1-60 MONTHS) | REQUESTED STARTING DATE | SHOW RELATED PRELIMINARY PROPOSAL NO. IF APPLICABLE |
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| $ **12,000** | **12** months | **05/01/05** | |

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- ☐ DISCLOSURE OF LOBBYING ACTIVITIES (GPG II.C)
- ☐ PROPRIETARY & PRIVILEGED INFORMATION (GPG I.B, II.C.1.d)
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- ☐ SMALL GRANT FOR EXPLOR. RESEARCH (SGER) (GPG II.D.1)
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- ☐ HIGH RESOLUTION GRAPHICS/OTHER GRAPHICS WHERE EXACT COLOR REPRESENTATION IS REQUIRED FOR PROPER INTERPRETATION (GPG I.E.1)

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|---|---|
| PI/PD DEPARTMENT<br>**Botany** | PI/PD POSTAL ADDRESS<br>**PO Box 3165**<br><br>**Laramie, WY 820713165**<br>**United States** |
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| CO-PI/PD | | | | |

# CERTIFICATION PAGE

## Certification for Authorized Organizational Representative or Individual Applicant:

By signing and submitting this proposal, the individual applicant or the authorized official of the applicant institution is: (1) certifying that statements made herein are true and complete to the best of his/her knowledge; and (2) agreeing to accept the obligation to comply with NSF award terms and conditions if an award is made as a result of this application. Further, the applicant is hereby providing certifications regarding debarment and suspension, drug-free workplace, and lobbying activities (see below), as set forth in Grant Proposal Guide (GPG), NSF 04-23. Willful provision of false information in this application and its supporting documents or in reports required under an ensuing award is a criminal offense (U. S. Code, Title 18, Section 1001).

In addition, if the applicant institution employs more than fifty persons, the authorized official of the applicant institution is certifying that the institution has implemented a written and enforced conflict of interest policy that is consistent with the provisions of Grant Policy Manual Section 510; that to the best of his/her knowledge, all financial disclosures required by that conflict of interest policy have been made; and that all identified conflicts of interest will have been satisfactorily managed, reduced or eliminated prior to the institution's expenditure of any funds under the award, in accordance with the institution's conflict of interest policy. Conflicts which cannot be satisfactorily managed, reduced or eliminated must be disclosed to NSF.

### Drug Free Work Place Certification

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Drug Free Work Place Certification contained in Appendix C of the Grant Proposal Guide.

### Debarment and Suspension Certification

(If answer "yes", please provide explanation.)

Is the organization or its principals presently debarred, suspended, proposed for debarment, declared ineligible, or voluntarily excluded from covered transactions by any Federal department or agency? Yes ☐ No ☒

By electronically signing the NSF Proposal Cover Sheet, the Authorized Organizational Representative or Individual Applicant is providing the Debarment and Suspension Certification contained in Appendix D of the Grant Proposal Guide.

### Certification Regarding Lobbying

This certification is required for an award of a Federal contract, grant, or cooperative agreement exceeding $100,000 and for an award of a Federal loan or a commitment providing for the United States to insure or guarantee a loan exceeding $150,000.

### Certification for Contracts, Grants, Loans and Cooperative Agreements

The undersigned certifies, to the best of his or her knowledge and belief, that:

(1) No federal appropriated funds have been paid or will be paid, by or on behalf of the undersigned, to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with this Federal contract, grant, loan, or cooperative agreement, the undersigned shall complete and submit Standard Form-LLL, ''Disclosure of Lobbying Activities,'' in accordance with its instructions.

(3) The undersigned shall require that the language of this certification be included in the award documents for all subawards at all tiers including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by section 1352, Title 31, U.S. Code. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

| AUTHORIZED ORGANIZATIONAL REPRESENTATIVE | SIGNATURE | DATE |
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| NAME | | |

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## PROJECT SUMMARY

This study will characterize the climatology underlying recent droughts, and will reconstruct spatial and temporal patterns of drought in the central Rocky Mountains using instrumental climate records (temperature, precipitation, and PDSI) and a multi-proxy approach (tree-ring widths and cellulose $\delta^{13}C$) for dendroclimatic reconstructions. Global climate change has become a significant ecological, political, and economic issue throughout the world. Regionally, a relatively long-term drought has persisted throughout the central Rocky Mountains, with negative impacts on the environment and the livelihood of local communities. Increasing the accuracy of future drought projections requires a glimpse into the past to look at long-term variability in precipitation and other factors associated with drought. Droughts are well documented in instrumental climate records from 1895-present, while tree-ring widths have been used successfully to extend these climate records back in time for hundreds of years. However, recent findings on declining tree-ring width sensitivity to climatic parameters (temperature, precipitation, and Palmer Drought Severity Index-PDSI), particularly at high elevations, have raised concerns about the accuracy of long-term reconstructions. Preliminary results from this research project have shown climate and tree growth relationships are becoming more complacent at the mid to high elevation sites starting around 1955. What is causing this shift is unknown, but may be related to recent warming and drying trends in the western U.S. This increasing complacency over time complicates the climate-tree growth relationship and subsequent drought reconstruction potential. It has been proposed that combining stable carbon isotope values with tree-ring widths could strengthen the climatic signal necessary for reconstructions. Since cellulose $\delta^{13}C$ has been found to correlate strongly with drought in semi-arid regions, it provides an opportunity to test a multi-proxy approach. For this project, an elevation gradient will be incorporated to address the question of tree-ring climate sensitivity over time. Limber pine (*Pinus flexilis)* will be sampled because of its abundance, longevity, extreme habitat tolerance, and adaptability to a wide elevation range. Inferences from these limber pine proxy records of annual and seasonal climate across an elevation gradient will improve our ability to identify spatiotemporal patterns of drought.

**Intellectual Merit:** Global climate change models predict higher temperatures and increased variability in precipitation which could affect drought frequency and intensity. This dendroclimatic reconstruction project is unique in that it is designed to fill a knowledge gap on drought in the central Rocky Mountains, specifically the North Platte River Basin of Wyoming. If there is a non-stationary climate issue in these data, it most likely is not unique to this region. The multi-proxy design of this project will address a knowledge gap as to whether $\delta^{13}C$ will strengthen the predictive ability of tree rings over time and space. The PI is ideally suited to undertake this multi-disciplinary project with her qualifications as a geochemist and ecosystem ecologist, and the CO-PI brings unique skills to the project as a vegetation ecologist and dendrochronologist. Considerable progress has been made on this project since its inception in spring, 2003.

**Broader Impacts:**

This project will advance understanding of several scientific disciplines, including ecology, biogeography, and geochemistry, by disentangling the complex ecological responses of tree ring width indices and isotopic composition to climate. This project will also provide a useful source of learning material for undergraduate and graduate courses in several departments open to both science and non-science majors. Lectures on the use of dendroclimatology and stable carbon isotopes will be incorporated into BOT 5700 (Vegetation Ecology), BOT 5730 (Plant Physiological Ecology), RNEW 5985 (Stable Isotopes), and G&R 4460 (Biogeography). We will broaden participation of underrepresented groups not only in our hiring, but by continuing to provide seminars to the Wyoming EPSCoR and NASA Space Consortium ìWomen in Scienceî K-12 Program. This project was designed and is presently being implemented by a female Ph.D. student who has returned to higher education after a decade in a natural resources-related position. Results will be disseminated through peer-review journals (i.e., Global Change Biology, Climate Change), conferences, and a website available through the UW Botany Department. Tree-ring data will be donated to the web-based International Tree Ring Database maintained by the NOAA Paleoclimatology Program. This research project will enhance the newly formed Terrestrial Ecosystem Ecology lab in the Botany Department and the Stable Isotope lab in Renewable Resources. Societal benefits will come from understanding drought in the central Rocky Mountain region and sharing these research results with the Wyoming state climatologist potentially to be used in land use planning and water conservation strategies at both the local and regional scale.

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For font size and page formatting specifications, see GPG section II.C.



*Proposers may select any numbering mechanism for the proposal. The entire proposal however, must be paginated. Complete both columns only if the proposal is numbered consecutively.

## PROJECT DESCRIPTION

### *Introduction*

Global climate change has become a significant scientific, political, and economic issue throughout the world (Woodhouse and Overpeck 1998). Regionally, global warming has manifested itself as a widespread and relatively long-term drought throughout the Rocky Mountains (Baron 2002). Frequent and persistent droughts in semi-arid regions such as the central Rocky Mountains, where inherent scarcity of water is exacerbated, can be devastating to both the environment and the local communities (Meko et al. 1995, Fye et al. 2003). For example, severe and sustained droughts afflicted most of the U.S. in the 1930′s and 1950′s leading to major agricultural and livestock losses (Fye et al. 2003). The need to reconstruct drought patterns is particularly acute when considering the potential for increased aridity caused by global warming (Manabe and Wetherald 1987, Melillo et al. 1995). Drought is the most limiting factor to tree growth in southwestern U.S. and can alter community structure and function (Fritts 1976, Meko et al. 1995, Allen and Breshears 1998, Swetnam and Betancourt 1998, Ogle et al 2000, Hidalgo et al. 2001). Recent and ongoing droughts remind us of the importance of understanding precipitation variability in western North America (Gray et al. 2004). Thus, increasing the accuracy of future drought projections requires a glimpse into the past to look at long-term variability in precipitation and other factors associated with drought.

Instrumental climate records rarely exceed 100 years, and therefore provide only a small sample of single- and multi-year anomalies. Tree-rings provide a means for developing long-duration climate proxies that can overcome many problems associated with the instrumental record. However, recent findings on declining tree-ring width sensitivity to climatic parameters (temperature, precipitation, and Palmer Drought Severity Index-PDSI), particularly at high elevations, have raised concerns about the accuracy of long-term reconstructions. Preliminary results from this research project have shown climate and tree growth relationships are becoming more complacent at the mid to high elevation sites starting around 1955. What is causing this shift is unknown, but may be related to recent warming trends in the western U.S. This increasing complacency over time complicates the climate-tree growth relationship and subsequent drought reconstruction potential.

It has been proposed that combining stable carbon isotope values along with tree-ring widths could strengthen the climatic signal necessary for reconstructions. Since cellulose $\delta^{13}C$ has been found to correlate strongly with drought in semi-arid regions, it provides an opportunity to test a multi-proxy approach. For this project, an elevation gradient was incorporated to address the question of tree-ring complacency over time. In addition, limber pine (*Pinus flexilis)* was sampled because of its abundance, longevity, extreme habitat tolerance, and adaptability to a wide elevation range. Inferences from these limber pine proxy records of annual and seasonal climatic cycles across an elevation gradient will improve our ability to identify spatiotemporal drought patterns. This study will attempt to assess the likelihood of drought in the central Rocky Mountains using instrumental climate records (temperature, precipitation, and PDSI) and a multi-proxy approach (tree-ring widths and cellulose $\delta^{13}C$) for dendroclimatic reconstructions in the central Rocky Mountain region.

### *Background*

*Climate change and drought:* Climate change models predict higher temperatures and increased variability in precipitation in the future, particularly for the southwestern U.S. (Gregory et al. 1997). General circulation models project that a doubling of atmospheric $CO_2$ in the near future will result in shifts in the spatio-temporal distribution of precipitation (Cubasch et al. 1995*).* Predicted climate change (higher temperatures and increased precipitation variability) may increase the frequency and intensity of drought (Lawford 1993, Hanson and Weltzin 2000). Droughts are well documented in instrumental climate records from 1895-present, while tree-ring widths have been used successfully to extend these climate records back in time for hundreds of years (e.g., LeBlanc and Foster 1992, Graumlich 1993, Villalba et al. 1994, Ettl and Peterson 1995, Loehle and Le Blanc 1996, Barber et al. 2000; Cook et al. 2001, Cullen et al. 2001, Peterson and Peterson 2001). Tree rings yield continuous, exactly dated proxies of annual climate that are highly replicable and often encompass multiple centuries (Fritts 1976, Cook and Kairiukstis 1990). However, recent findings on declining tree-ring width sensitivity to climate (temperature, precipitation, and PDSI), particularly at high elevations, have raised concerns about the reliability of long-term reconstructions (e.g., Briffa et al. 1998).

*Climate-tree growth relationship:* Greater tree-ring variation is associated with greater environmental stress (Fritts 1976). Testing the temporal stability of this climate-tree growth relationship has fundamental implications for reconstruction of natural climate variability (Biondi 2000). All the regression techniques used in dendroclimatic reconstructions assume that climate-tree growth relationships are stable over time (Biondi 2000). Altered climate sensitivity of tree-rings records has recently been reported in connection with global change phenomena (Briffa et al. 1998, Biondi 2000, Barber et al. 2000, Tardif et al. 2003). Looking at large-regional-scale relationships at high latitudes, Briffa et al. (1998) found that during the second half of the 20th century, the decadal-scale trends in wood density and summer temperatures have increasingly diverged as wood density has progressively fallen. The divergence between tree growth and mean summer temperatures probably began as early as the 1930′s; became recognizable particularly at northern latitudes after 1960, and has continued to increase since then (Briffa et al. 1998). Thus, recent correlations may not be reliable indicators of the strength or nature of relationships in the past (Briffa et al. 1998). Possibly the positive linear thermal response of the trees breaks down above some absolute threshold (lower soil moisture exerts increasing stress), but actual causes are unknown (Briffa et al. 1998). Whatever the cause, this change in tree-growth response, particularly at high elevations, has important implications for studies of past and future climate change.

*Climate-tree growth and high elevation:* Recent studies of worldwide meteorological data from high elevation stations have shown that air temperature has increased during the 20th century for most areas (Diaz and Bradley 1997). Greatest warming was observed in the mean monthly minimum temperatures (Rolland et al. 1998, Beniston et al. 1997). Past research indicates that the northern boundary of the boreal forest is affected by temperature; whereas, the southern boundary has been related to moisture limitation (Shugart 1984, Earle et al. 1994, Hogg 1994, Briffa et al. 1995). Temperature effect is consistent with the fact that the cambial reactivation of evergreen conifers is triggered by a rise in temperature and the ability of trees to grow in high elevation sites is related to length of growing season (Tranquillini 1979). Alaska stations show a strong warming trend in the growing season over the past 50 years which is hypothesized to deplete already limited soil moisture (Barber et al. 2000). Tardif et al. (2003) found an increase in the annual temperature sensitivity from 1950-1994 in the central Pyrenees. Data for this Pyrenees region shows a drastic increase of minimum temperatures, a decrease of diurnal temperature ranges, and an increase of temperature variability since 1940 (Dessens and Bucher 1997). Since the beginning of the 20th century, increasing dissimilarity was observed among chronologies, indicating that climate was less limiting to growth (Tardif et al. 2003). Warmer, more humid conditions with low year-to-year variability may have brought a relaxation of the elevation gradient allowing local growth conditions to dominate (Tardif et al. 2003).

*Climate-tree growth and stable carbon isotopes:* Increased complacency in climate-tree growth relationships complicates singular use of tree rings as a proxy for climatic reconstructions, thus stable carbon isotopes have been proposed as an additional proxy. Since cellulose $\delta^{13}C$ has been found to correlate strongly with drought in semi-arid regions (Leavitt and Long 1989, Leavitt 1993), it provides an opportunity to test a multi-proxy approach. By combining more than one proxy where each one responds to different climate drivers, the strength of the climate signal can be enhanced (McCarroll et al. 2004). For example, a growth reduction caused by moisture stress rather than low temperatures would show a decline in ring width and latewood density with an increase in $\delta^{13}C$ of latewood cellulose (McCarroll et al. 2004). Often, tree-ring widths and $\delta^{13}C$ values are not correlated which indicates the two variables are responding to different factors (Mazany et al. 1980, Brooks et al. 1998). Furthermore, the use of $\delta^{13}C$ and tree ring data has provided a rich perspective on differences and underlying mechanisms of drought response in trees (Mazany et al. 1980, Livingston and Spittlehouse 1993, McNulty and Swank 1995, Panek and Waring 1997, Saurer et al. 1997, Brooks et al. 1998, Ferrio et al. 2003).

*Cellulose $\delta^{13}C$ and drought:* Cellulose is about 40% carbon, and the natural abundance of stable carbon isotopes in the annual rings of trees tracks environmental changes and climate (Panek and Waring 1995). Carbon isotope ratios can determine the nature and strength of many climate signals including temperature, precipitation, and air relative humidity, particularly in pines (McCarroll and Pawellek 2001). Stable carbon isotope analysis on tree cellulose compliments traditional dendroclimatology by providing a more detailed calibration of local climate by season (Livingston and Spittlehouse 1996). Stable carbon isotope composition ($\delta^{13}C$) records change with the concentration of $CO_2$ in the stomatal chambers (McCarroll and Pawellek 2001). It reflects the balance between stomatal conductance (*g*) and photosynthetic rate (*A*). Years with greater moisture stress, and the portions of the growing season with greatest moisture stress, correspond to narrow tree rings and high $\delta^{13}C$ values in ring cellulose (Leavitt and Long 1989, Leavitt 1993). Under moisture stress, reduction of stomatal conductance leads to lower internal $CO_2$ concentrations and reduced preferential fixation of $^{12}CO_2$ relative to $^{13}CO_2$; hence, elevated $\delta^{13}C$ values result during cellulose formation (Farquhar et al. 1982).

*Cellulose $\delta^{13}C$ and elevation:* Shifts in $\delta^{13}C$ at the intraspecific level are consistently observed over altitudinal gradients (Korner et al. 1988, Vitousek et al. 1990, Marshall and Zhang 1994, Sparks and Ehleringer 1997). A global survey of carbon isotope discrimination of plants (forbs, shrubs, and trees) along altitudinal gradients (5600m) have found decreased discrimination (indicative of increased *A/g*) at higher altitudes (Korner et al. 1988). Carbon isotope ratios of leaves increased linearly with altitude, but slopes of this relationship varied among several species of evergreen conifers (Hultine and Marshall 2000). Previous studies have reported similar increases in $\delta^{13}C$ of leaves along altitudinal gradients (Korner et al. 1988, Vitousek et al. 1990, Marshall and Zhang 1994, Adams and Kolb 2004). Mechanisms underlying the $\delta^{13}C$ and altitude trend are unknown. Possibly, decreasing barometric pressure, $CO_2$ partial pressure, water vapor partial pressure, and temperature with increasing altitude may result in higher stomatal conductance for a given stomatal aperture (Smith and Donohue 1991). Limber pine was found to have greater stomatal sensitivity to vapor pressure deficit than ponderosa in a high-elevation meadow in northern Arizona (Fischer et al. 2002). This finding suggests that drought, which is often accompanied by high vapor pressure deficit, has a greater negative effect on stomatal aperture and photosynthesis of limber than ponderosa pine.

*Climate and limber pine:* Limber pine (*Pinus flexilis*) is inherently a good dendroclimatic indicator species because it has well preserved tree rings, longevity (>1000 years), extreme habitat tolerance (xeric, windy, and rocky sites), and adaptability to a wide elevational range (<1700 to >3200m) (Johnson 2001). These ideal characteristics address many of the underlying assumptions necessary to perform and interpret dendroclimatology. Principle assumptions include 1) physical and biological processes that link current environmental processes with current patterns of tree growth must have been in operation in the past, 2) rates of plant processes are constrained by the primary environmental variable that is most limiting such as temperature or moisture, 3) site selection is based on criteria that will produce tree-ring series sensitive to the environmental variable being examined; trees that are especially responsive to drought conditions can usually be found where rainfall or soil moisture is limiting, and 4) a tree species will be more sensitive to environmental factors at elevational limits of its range (Grissino-Mayer 2003). Limber pine was found to be an excellent species for dendroclimatic reconstruction of annual precipitation in the Northern Great Plains of Canada (Case and MacDonald 1995).

### *Research Hypotheses*

***Hypothesis 1:*** Narrow tree rings and elevated values of $\delta^{13}C$ (both strong indicators of drought) will be found at high elevation sites during years of decreased winter precipitation (snowpack), and at low elevation sites during years with decreased summer precipitation (rain).

***Hypothesis 2:*** Temperature sensitivity in tree-ring widths at high elevation sites has shifted over the last century, becoming more responsive to effective precipitation (and less responsive to temperature), due to longer growing seasons and loss of snowpack in the past 50 years.

***Hypothesis 3:*** Precipitation sensitivity in tree-ring widths at low elevation sites has shifted over the last century, becoming more responsive to spring moisture, due to a warming trend and an earlier growing season in the past 50 years.

***Hypothesis 4:*** Palmer Drought Severity Index (PDSI) will be most closely associated with tree-ring widths and $\delta^{13}C$ values at all elevations due to its integrative measure assessing severity of dry or wet weather periods.

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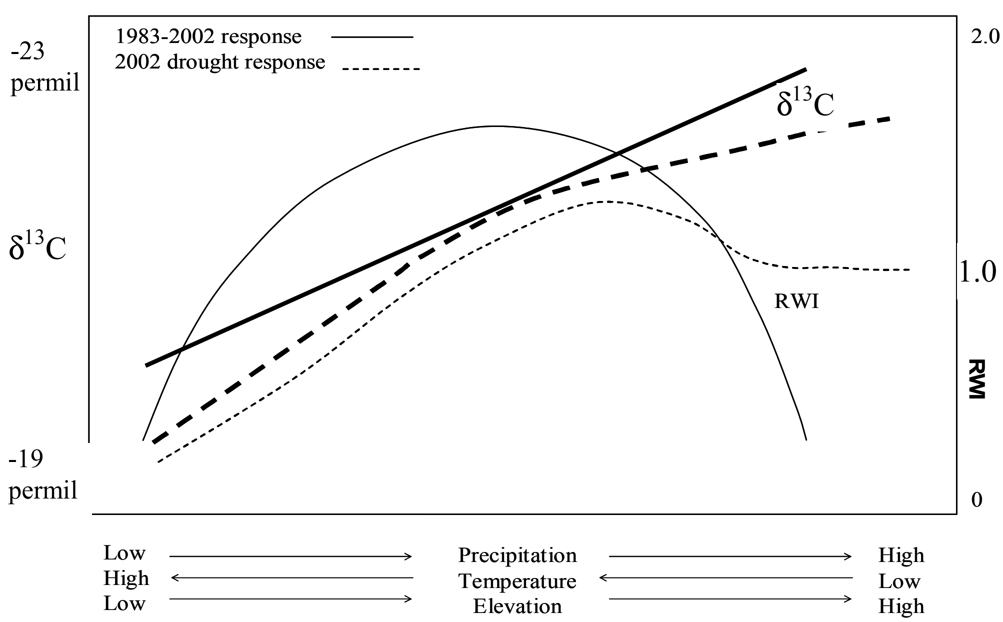


**Figure 1.** This conceptual model is based on preliminary findings from 1983-2002 climate, ring-width indices (RWI), and $\delta^{13}C$ values. Data from year 2002, considered to be a significant drought in the central Rocky Mountains, was used to develop a hypothetical warming/drying response. The $\delta^{13}C$ values increased (were less negative), during the drought of 2002 (darker dashed line), as compared to a 20-year period (darker solid line). Increased $\delta^{13}C$ values were most evident at the low and high elevations. RWI decreased from the low to mid-elevations during the drought of 2002 (lighter dashed line) as compared to a 20-year period (lighter solid line).

However, RWI from the high elevation site had moderate RWI (≈1.0), indicating less sensitivity, during a known drought year. This pilot study suggests that a multi-proxy approach combining $\delta^{13}C$ and RWI could strengthen the overall climatic signal necessary for reconstructions.

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### *Research Plan*

*Study area:* All study sites are located within the North Platte River Basin in southeastern Wyoming. The North Platte originates in the mountains of Colorado and flows north towards Casper, Wyoming where it turns towards the southeast and eventually flows into Nebraska. The river and its tributaries, the Encampment, Sweetwater, Medicine Bow and Laramie, drain most of the southeastern quarter of Wyoming (Figure 2). The basin covers about 28,000 square miles. Several tributaries drain from mountainous areas on the eastern continental divide and the Snowy Range. The South Platte River unit contains Cheyenne, the state's largest urban area and its main streams are Lodgepole and Crow Creeks, which originate on the eastern slopes of the Laramie Range. These streams flow east into Nebraska and Colorado respectively.

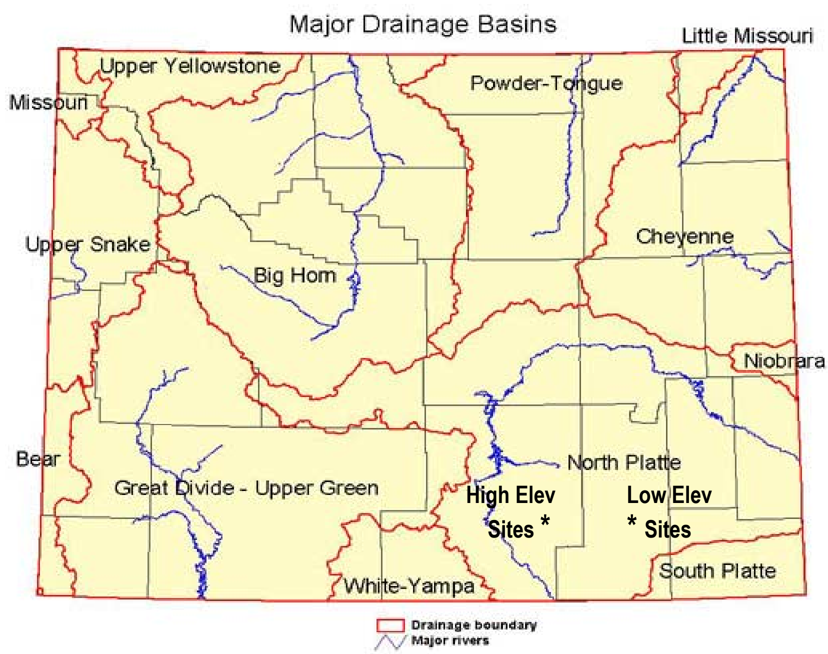


**Figure 2.** Study sites within the North Platte River Basins of Wyoming.

Vegetation along this project's elevational gradient consists of mixed-grass prairie at the lower end of the basin (1800 m), sagebrush steppe, semi-arid woodlands, and riparian corridors along the way as you move west and upward to the Laramie Range (2500 m). Further west heading towards the eastern Continental Divide, mixed forest, subalpine meadows, and finally alpine treeline are found in the Snowy Range Mountains (3500 m). Study sites range in elevation from 2350 to 3150 m with surface geology dominated by Precambrian granite (Knight 1994). Precipitation for the lower elevation study sites average 386 mm/year with temperatures averaging a maximum of 14°C to a minimum of 11°C. For the higher elevation sites in the mountains, precipitation averages 497 mm/yr with temperatures ranging from 5°C to -9°C (Martner 1986).

**Table 1**. North Platte River Basin, Wyoming research site characteristics and tree core data.

| **Site ID and Lat./Long.** | **Subplot ID - # trees sampled** | **Elevational Range (m)** | **Cores collected (5mm)** ***for tree ring widths*** | **Cores collected (12mm)** ***for isotope analysis*** | **Total cores** |
|---|---|---|---|---|---|
| Rock Creek **RC** *41deg10N 106deg09W* | RCa - 8<br>RCb - 12 | 3130 to 3150 | 16<br>24 | 17<br>21 | *78* |
| Centennial Ridge **CR** *41deg16N 106deg09W* | CRa - 15<br>CRb - 6 | 2920 to 2985 | 34<br>12 | 27<br>3 | *76* |
| Pilot Hill **PH** *41deg16N 105deg25W* | PHa - 10<br>PHb - 10 | 2660 to 2675 | 23<br>25 | 15<br>15 | *78* |
| Headquarters Road **HR** *41deg13N 105deg21W* | HRa - 10<br>HRb - 3<br>HRc - 8 | 2475 to 2500 | 22<br>24<br>21 | 14<br>3<br>18 | *102* |
| Middle Crow **MC** *41deg10N 105deg17W* | MCa - 8<br>MCb - 5<br>MCc - 8 | 2350 to 2380 | 16<br>11<br>16 | 24<br>9<br>12 | *88* |
| | *Trees = 103* | | *5mm = 244* | *12mm = 178* | **422** |

*Tree ring chronology:* Tree cores from limber pine (*Pinus flexilis*) were collected from twenty trees at each of five study sites along an elevational gradient (2300-3200m) during summers of 2003 and 2004. Trees at the limits of their distributions are growing under stress (Fritts 1976) and tend to provide a stronger climatic response signal, thus lower and higher elevational limits of limber pine were included in this study. Using an elevational gradient sampling scheme will also provide additional insight into limber pine sensitivity to seasonal moisture (winter snowpack vs. summer rain) which may affect their upper and lower treeline limits (Brooks et al. 1998). We took two (5mm) increment cores from opposing sides of each tree (Cook and Kairiukstis 1990) (Table 1). Tree ring cores were mounted and progressively sanded up to ≤ 600 grit. Each core was subjected to standard graphical dating methods (Stokes and Smiley 1968, Cook and Kairiukstis 1990). Rings were measured to the nearest 0.01 mm and the COFECHA program (Holmes 1999) was used to confirm the cross-dating by comparing ring-width measurements among all series within a site. Dating was verified for a total of 167 series among the five sites with series inter-correlations high ($r = 0.459$ to 0.713) (Table 2). The ARSTAN program (Cook and Holmes 1997) was used to create chronologies and ring width indices (RWI) with either negative exponential or linear spline detrending (negative or zero slope) to preserve climate-related variation at both high and low frequencies. All chronologies in this study contain significant autocorrelation at lags of 1-2 years. Dendrometer bands were installed June of 2004 on one tree for each of three study sites (low, mid, and high elevation) for periodic circumference-growth measurements to supply information on growing season length. Measurements need to be taken for at least two growing seasons before interpretation to let the dendrometers settle into place (Clark et al. 2000).

**Table 2.** Characteristics of tree-ring chronologies for the five limber pine study sites.

| Site | Chronology length | Number of dated series | Series Inter-correlation | Mean sensitivity |
|---|---|---|---|---|
| **RC** | 1892-2002 | 27 | 0.540 | .248 |
| **CR** | 1836-2002 | 11 | 0.459 | .306 |
| **PH** | 1701-2002 | 54 | 0.647 | .245 |
| **HR** | 1850-2002 | 47 | 0.7$^{13}$ | .328 |
| **MC** | 1894-2002 | 28 | 0.699 | .325 |

*Climate-tree growth relationships:* To determine suitability of chronologies for use in precipitation reconstruction, climate-tree growth relationships were investigated using correlation analyses that compared tree-ring widths to instrumental climate records obtained from the National Climatic Data Center - NCDC (http://www.ncdc.noaa.gov/oa/ncdc.html). Comparisons included using RWI versus monthly and seasonal precipitation, temperature, and Palmer Drought Severity Index - PDSI (Palmer 1965, Alley 1984) records from NCDC state climate divisions dated from 1895 to present. Variables with lags of ± 1 year and variable growing seasons and months were examined using the DENDROCLIM2002 program which provides a bootstrapped correlation and response function on a single interval (Biondi and Waikul 2004). Each site has significant correlations ($p \leq 0.05$) with all three climate parameters from 1895 to 2002 (Table 3). However, notice the loss of sensitivity, particularly for the high elevation site (RC) starting around 1955, thus this climate-ring widthrelationship appears to be non-stationary. After 1955, there are also seasonal shifts from summer to spring months at the mid to higher elevation sites (CR and PH) with no apparent change at the lowest elevation sites (HR and MC). Despite this, PDSI remains highly correlated with all sites except the highest one (RC) where the signal disappears after 1955.

**Table 3.** Significant correlations (P<0.05) for ring-width indices and NCDC climate parameters for two periods.

| | **RC High Elevation** | **CR** | **PH Mid-Elevation** | **HR** | **MC Low Elevation** |
|---|---|---|---|---|---|
| Temperature + RWI *1895-2002* | Previous July (-) | Previous June (-) | Previous Sept (+) | Present June (-) | Present Feb (+) |
| ***1955-2002*** | ***NO correlations*** | ***Shift to May*** | ***Shift to May*** | *No change* | *No change* |
| Precipitation + RWI *1895-2002* | Prev Dec/pres Jan (+) | Previous Oct (+) | Present June (+) | Present June (+) | Present June (+) |
| ***1955-2002*** | ***Shift to Oct*** | ***Shift to May*** | ***June*** | *No change* | *No change* |
| PDSI + RWI *1895-2002* | All prev/pres months (+) | All prev/pres months (+) | Present Nov/Dec (+) | All prev/pres months (+) | All prev/pres months (+) |
| ***1955-2002*** | ***NO correlations*** | ***Jan/Feb/Mar*** | *No change* | *No change* | *No change* |

*Carbon isotopes:* Stable carbon isotope analysis in tree rings is an important method for extracting climate data from relatively complacent trees such as limber pine (Mazany et al. 1980). For carbon isotopic analysis, three to four (12mm) increment cores were collected from ten trees at the five study sites (Leavitt and Long 1984). Each year's growth was carefully separated with a razor knife under a binocular scope. Then, latewood was separated for use in this project. Several researchers have found that latewood isotopic composition is more sensitive than earlywood to environmental variables such as solar radiation, air temperature, rainfall, and relative humidity (Livingston and Spittlehouse 1996, Pendall 2000). For this pilot project, annual latewood sections (1983 to 2002 = 20 yrs) were pooled for each tree to better represent $\delta^{13}C$ trends (Leavitt and Long 1984). Samples were ground to 40 mesh and bagged for reduction to holocellulose using the method described in Leavitt and Danzer (1993). Two tree samples (0.15 mg) for each of the five study sites were analyzed for $\delta^{13}C$ by elemental analysis-mass spectrometry (Leavitt and Danzer 1993, McCarroll and Loader 2004). Greatest variation was found at the lowest and highest elevation sites, suggesting greater sensitivity at the range limits of limber pine. Values from the two trees were averaged and correlation analysis was done between NCDC climate parameters from 1983 to 2002 and latewood $\delta^{13}C$ values (Table 4). Notice that the significant seasonal signal is different than those found with ring-width indices (Table 3), demonstrating the potential to improve reconstructions when used with RWI.

**Table 4.** Correlations for $\delta^{13}C$ and NCDC climate parameters (1983-2002).

| Site | RC | CR | PH | HR | MC |
|---|---|---|---|---|---|
| **Temperature + $\delta^{13}C$** | | Present Jan/Feb (-) | | Present Oct (-) | Present Dec (+) |
| **Precipitation + $\delta^{13}C$** | | Present Spring (-) | Present GS (-) | | Present Spring (-) |
| **PDSI + $\delta^{13}C$** | | | Present Spring (-) | Present July (-) | Present Fall (-) |

### ***Proposed Research Needs***

*Tree ring chronology:* Additional 12-mm cores will be collected from the low and high elevation sites for extending the record back in time and increasing the sample size for RWI and $\delta^{13}C$ analyses. Cores will be brought back to the lab, sanded and measured using standard dating methods (Stokes and Smiley 1968). Once cross-dating is quality checked using the COFECHA program (Holmes 1983), cores will be ready for cutting. This chronology also will be extended in time with limber pine datasets (and other similar species) from this region using the International Tree Ring Data Bank (ITRDB). For example, tree-ring widths are available (1700 - 1977) for eastern Wyoming from Stockton and Meko (1983). Because autocorrelation is likely caused or amplified by biological factors rather than climate (Fritts 1976), a low-order autoregressive-moving-average (ARMA) filter within the ARSTAN program will be applied to remove this high-frequency persistence (Box and Jenkins 1970). Since sample depth declines in the early portions of these chronologies, a Subsample Signal Strength (SSS) will be used to assess replication through time at each site (Wigley et al. 1984).

*Climate-tree growth relationship:* Tree growth will be compared against snow (Brooklyn Lake, WY SNOTEL) for the high elevation site in the Snowy Range Mountains. Research the Historical Climatology Network (http://www.ncdc.noaa.gov/oa/climate/research/ushcn.html) for climate records applicable to these study sites. These particular records have been adjusted for measurement and location biases with missing data estimated using neighboring stations (Easterling and Peterson 1995).

*Dendroclimatic reconstruction:* Stepwise multiple linear regression analysis will be used to develop statistical relationships between precipitation and the most highly correlated tree-ring chronologies (Watson and Luckman 2001). The period common to both the tree-ring chronologies and divisional climate records will be divided into even and odd numbered years. One set will be used to calibrate the model and develop an equation, then the other set of data will used to validate the model (split-sample validation) (Gray et al 2004). The final regression equation to will be used to generate long-term reconstructions.

In this project, concerns with the potential non-stationarity of climate data over time will be addressed with additional subsetting procedures (e.g., 1895-1954 and 1955-2002) to assess the model, even though transfer functions are calibrated over the most recent decades, and may not ìfixî this problem. Thus, an additional check will be to correct for the greater variance during years when fewer chronologies are available to contribute to the average (which may be the case for the available climate data). This effect can be corrected for by scaling by the square root of the effective number ($n'$) of independent samples available in each year, where $n' = n/[1 + (n - 1)r]$, where $r$ is the mean inter-site correlation between the $n$ chronologies, a measure of the regional-scale common signal (Briffa et al. 1998). After correction, each regional mean time series will be normalized. Autoregressive integrative moving averages (ARIMA) and differencing will be tested as well.

*Carbon isotopes:* To verify the possibility of using $\delta^{13}C$ as a proxy with tree-ring widths and climate, an additional 30 annual rings from the low and high elevation sites need to be cut, processed, and analyzed by elemental analysis/mass spectrometry, totaling a 50-year sample size. In addition, 2 to 3 more trees per site will increase the replication to 4 trees per site, which should strengthen the $\delta^{13}C$ climate relationships. This 50-year time frame was chosen to include the 1950′s dry period for comparison to more recent droughts. Improved correlations should be found at the high elevation site after including additional depth and replication of samples. Mass spectrometer analysis will be done at the University of Wyoming Light Stable Isotope Facility. Collection of additional 12mm cores in the spring of 2005 will provide a larger cellulose sample for particularly small ring years (e.g. 2002).

## SIGNIFICANCE AND BROADER IMPACTS

Global climate change models predict higher temperatures and increased variability in precipitation, both spatially and temporally, in the western United States. These predictions suggest increased frequency and intensity of drought which, ultimately, may affect the environment and humankind. Many climatic reconstructions have been successful in forecasting the potential range of climatic extremes by backcasting using tree rings, ice cores, corals, peatlands, lake cores, or packrat middens. This project is unique in that it is designed to fill a knowledge gap in the central Rocky Mountains, specifically the North Platte River Basin of Wyoming. Yet, results can be extrapolated to other semi-arid regions of the western U.S. including the Front Range of Colorado and the downstream state of Nebraska. However, to do reliable long-term reconstructions, particularly if non-stationary climate data exists, a closer look at short-term trends is required. If a phenomenon is identified, it most likely is not unique to this region, and will affect future attempts at climate reconstructions. Accounting for this phenomenon will open the door to potentially new approaches to time series analysis that can be utilized in other regions. The multi-proxy design of this project will also address a knowledge gap as to whether $\delta^{13}C$ will strengthen the predictive ability of tree rings in this semi-arid region, and if it can help adjust for the recent warming/drying trend that appears to be affecting tree-ring sensitivity.

## PERSONNEL AND RESPONSIBILITIES

Pendall will be responsible for overall administration and coordination of this project. She will supervise a graduate student who will be involved in all activities as listed in the work schedule. The graduate student will co-supervise an undergraduate assistant who will participate to some extent in all aspects of the project. This project is very labor intensive and requires meticulous work by a well trained technician to achieve the best results. The PI and Co-PI will pursue avenues to insure that underrepresented groups participate in this research project.

## WORK SCHEDULE

Field work will commence in mid to late May, 2005 at the low elevation site with collection of additional 12-mm cores, and continue through June, 2005 at the high elevation site. Cores will be brought back to the lab for sanding in preparation for measuring using standard dating methods (Stokes and Smiley 1968). Once cross-dating is quality checked using the COFECHA program (Holmes 1983), cores will be ready for cutting. The Ph.D. student will train and closely supervise an undergraduate student in preparation of tree-rings for isotope analysis. This will involve slicing tree rings, ball milling into a fine powder and sealing in ANKOM pouches. Chemical processing will be initiated as soon as individual pouches are ready, probably in late summer or early fall. Sealed pouches (45 per run) are put into a soxhlet apparatus for a toluene/ethanol stage, then a bleaching stage which all combined takes 6 days (Leavitt and Danzer 1993). Since 450 (2 sites by 4 trees by 50 years) samples need to be processed (this includes 10% standards), cellulose preparation will take 60 days. When this stage is completed, cellulose is extracted from the pouches and weighed for the elemental analysis-mass spectrometry stage at the University of Wyoming Light Stable Isotope Facility. Final calculations of $\delta^{13}C$, data analysis, manuscript preparation, and submittal will continue through 4/30/06.

**Summary of Requested Expenses:**

*Personnel:* One undergraduate student @ $7.50/hr

| | |
|---|---|
| • Summer session (100 hrs/mth for 3 months) | $2250. |
| • Fall and Spring semester (60 hrs/mth for 9 months) | $4050. |
| *Travel*: Field collection will be 10 days and each study site is 110 miles roundtrip @ 0.35¢/mile | $ 385. |
| *Materials and supplies:* | |
| • Sandpaper, cutting blades, and ANKOM pouches. | $ 150. |
| • Chemical supplies including toluene, ethanol, sodium chlorite, and glacial acetic acid | $ 325. |
| • Safety gear including gloves and respirators and glassware including flasks and beakers | $ 340. |
| • Stable isotope lab costs $10.00/sample (450 samples) | $4500. |
| TOTAL | $12,000. |

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