Earlywood, Latewood, and Adjusted Latewood Correlations to Precipitation: A Test Case from the Khangai Mountains, Mongolia

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ABSTRACT

The Khangai Mountains of central Mongolia provide important ecosystem services to the surrounding region as the headwaters for a number of river systems and critical pasture for the animal herds of nomadic pastoralists. The mountains also provide a long-term record of regional moisture variability preserved within the tree-rings of Siberian larch (*Larix sibirica*) forests. Ring width measurements are commonly used to statistically reconstruct the hydroclimatology of a region based on the correlation of ring widths to precipitation and/or streamflow. Tree cores were collected, cross-dated, and the ring widths were measured from a site near Jargalant *bagh* in northern Bayankhongor *aimag*. Seasonal precipitation totals for the period from 1962 to 2012 were compiled from several meteorological stations surrounding the site. These historical precipitation values were compared to indices of total (TW), earlywood (EW), and latewood (LW) ring widths generated from a series of 16 cores. Nearly 70% of the annual precipitation in the Khangai region falls during the summer season (June, July, August), resulting in stronger correlations of ring widths (TW, EW and LW) to the previous year's summer precipitation than to the current year's spring or previous year's fall precipitation. The dependence of LW widths on antecedent EW ring widths masks any correlation to spring and fall precipitation. This dependence was removed using linear regression, resulting in the discovery of a negative relationship between the adjusted latewood (LW_a) ring widths and precipitation in both spring of the current year and fall of the previous year. This indicates that LW_a captures a different climate signal not detectable when working with the original LW, EW or TW measurements. Correlations of EW with (previous year's) summer precipitation were similar in value to correlations of TW with (previous year's) summer precipitation, suggesting that additional measurements of ring width may not be needed for use in reconstructing long-term summer precipitation variability. However, LW_a and the associated measurements required for its calculation may be potentially useful for reconstructing spring and fall precipitation patterns in summer precipitation-dominated hydroclimate systems.

Keywords: Mongolia, tree-rings, larch, precipitation, earlywood, adjusted latewood, paleoclimate

INTRODUCTION

The Khangai Mountain region covers nearly 120,000 square kilometers of forest steppe, steppe, and desert steppe ecozones across three *aimags* in central Mongolia. The mountains are the headwaters for a number of important river systems and provide critical pasture for the animal herds of nomadic pastoralists on a seasonal basis (Fernandez-Gimenez, 2000). Precipitation of the region is dominated by synoptic scale disturbances in the summer months of June, July, and August during which nearly 70% of annual precipitation falls (Sato et al., 2007). Spring and fall precipitation patterns are also important for the greening of vegetation needed for grazing and for sustaining natural water supplies for domestic and agricultural uses (Yu et al., 2003; Fassnacht et al., 2011).

While temperatures in the region have been warming significantly over the period of record, patterns of precipitation change are less clear (Batima et al., 2005; Dagvadorj, 2010; Jamiyansharav, 2010; Fassnacht et al., 2011; Venable *et al.*, 2012). Observational climate records for the region are fairly short, extending from the mid-1960's to the present. Here, we use tree-rings of Siberian larch (*Larix sibirica*) to provide a longer-term record of moisture variability in the Khangai region.

Of particular interest is discerning differences in seasonal precipitation patterns of the region to better understand changes through time to the local hydroclimatology. Traditional dendroclimatologic analysis correlates measurements of total ring width to climate variables such as temperature and precipitation (i.e. Fritts, 1976). Past precipitation reconstructions in Mongolia have used total ring widths due to the relatively strong relations of summer precipitation (previous and current year's) to total ring width (e.g. Jacoby *et al.*, 1999; Pederson *et al*., 2001).

More recent research suggests that the widths of the earlywood and latewood components of tree-rings have differing, and often better correlations with seasonal precipitation than total ring widths, especially in regions with bi-annual and monsoonal precipitation patterns (Meko and Baisan, 2001). This has proved particularly useful in the American Southwest when trying to reconstruct warm-season precipitation patterns from total ring widths that correlate more highly with cool-season precipitation patterns (Stahle et al., 2009, Griffin et al., 2011). In Mongolia, only a few published studies have used earlywood and latewood to examine seasonal temperature and/or precipitation patterns (De Grandpré et al., 2011; Dulamsuren et al., 2011; Khishigjargal et al., 2014). The goal of this study is to explore the correlation of total, earlywood, and latewood ring widths from tree cores recently collected in Mongolia with seasonal precipitation data from the Khangai region for potential use in hydroclimatic reconstructions.

METHODS

Study Area and Tree Cores

Tree cores were collected from 25 Siberian larch (*Larix sibirica*) trees at a dry mountain site (46.7 degrees north latitude, 100.9 degrees east longitude) near Jargalant *bagh* in Erdentsogt *soum* of Bayankhongor *aimag* in the Khangai Mountain region of Mongolia during June of 2012 (Figure 1). Older trees typically exhibited heart-rot, and there was recent evidence of some cutting in the stand and fire scarring of a few stumps and trees at the higher elevations. Of the original 53 cores collected for analysis, 16 cores from younger trees (between about 50 and 100 years of age) were selected for analysis since latewood tends to stabilize and decrease in size as a tree ages. Older trees often possess latewood with greatly reduced signal strength and are more difficult to measure accurately (Griffin et al., 2011).

The subset of cores were prepared and cross-dated using standard dendrochronological methods (e.g. Stokes and Smiley, 1996). The dplR package in R was used to statistically verify the accuracy of hand cross-dating and to iteratively detrend the ring width measurements using a spline function with a frequency response of 50% at a wavelength of 2/3 the length of the series intended to isolate climate as the dominant signal in the standardized ring widths (Cook, 1985, Bunn, 2008; Bunn, 2010; R Core Team, 2014). Robust chronologies for earlywood, latewood and total ring widths were built for the site by merging the series using a robust mean function with an Expressed Population Signal (EPS) of at least 0.85 for the total ring width chronology (e.g. Wigley et al., 1984, Briffa and Jones, 1990; Griffin et al., 2011) (Table 1). Adjusted latewood indices were calculated at the site level in a manner similar to previous studies to remove the dependence of latewood widths on antecedent earlywood widths (e.g. Griffin et al., 2011; Meko and Baisan, 2011; Stahle et al., 2009).

Precipitation Data

A majority of the precipitation in the Khangai region of Mongolia occurs in what locals describe as quasi-monsoonal rainfall during the months of April through September, defined here as the wet season. The dry season extends from October through March, and for the current tree-ring year it includes most of the period of dormancy for larch (previous year's October through the current year's March). Seasonal precipitation was defined as spring from March through May, summer as June through August, fall as September through November, and winter as December through February. Peak rainfall amounts generally occur during July and August and averaged 69.2% of annual rainfall during the period of record.

Precipitation totals for the tree-ring site were produced using basic inverse distance weighting from three long-term monitoring stations (Bayankhongor, Galuut, and Tsetserleg), with missing data filled by values from the Global Precipitation Climatology Center (GPCC) monthly grids (Schneider *et al.*, 2014) (Figure 1).

RESULTS

Correlations of current and previous years' total annual, wet/dry season (six-month aggregates), and seasonal precipitation (three-month aggregates) with total, earlywood, latewood and adjusted latewood ring widths from the current year were performed. Only significant results are (at the p<0.05 level) presented here (Table 1). The strongest correlations are positive for total and earlywood ring widths with previous year's total, summer, and wet season precipitation. Latewood correlates positively with previous year's summer precipitation and negatively with the dry season of the current year (previous October to current March). Unlike latewood, adjusted latewood has no significant correlation with the previous year's summer precipitation. Instead it negatively correlates with fall precipitation (September-November) and spring precipitation (March-May), both of the previous year. Latewood and adjusted latewood both have negative correlations of similar magnitude with the current years dry season precipitation.

DISCUSSION AND CONCLUSIONS

There is little difference between the total and earlywood ring width results in terms of improved correlation magnitude with wet season and summer precipitation, suggesting it may not be worth the extra measurement effort to use earlywood in reconstructions as compared to total ring width. Significant correlations with previous year's July and August precipitation were noted for total, earlywood, and latewood (but not for adjusted latewood) ring widths from larch in a region northeast of our study area (De Grandpré et al., 2011). Khishigjargal et al. (2014), also found positive correlations of total ring width with June (included in our summer category) and previous year's late season precipitation (included in our category of wet) in the same region. They found a negative correlation between December precipitation (included in our dry category) and ring width. A study by Dulamsuren et al. (2011), in the western Khenty Mountains had a similar result. Our analysis results did not support any significant correlations with winter precipitation and ring width per se, though the dry season defined here would include December/winter precipitation.

The difference between the correlation of latewood and adjusted latewood to previous year's wet season and summer precipitation illustrates the relation between earlywood and latewood and the need to remove that dependence in the Jargalant cores. There is no correlation between total previous year's precipitation with latewood or adjusted latewood probably because of the dominance of the summer wet season signal and its strong relation to earlywood and total ring width formation. No correlation may also be a result of the influence of temperature on latewood development, though summer moisture stress may influence the thickness of latewood formation (De Grandpré et al., 2011).

Affirming previous results in Mongolia (e.g. De Grandpré et al., 2011), correlations of previous year's summer precipitation with total and earlywood widths are the strongest found, with correlation coefficients of r=0.46 and r=0.47 respectively (Table 1). Additional measures of ring-with (i.e. EW, LW and LW_a) show increased and/or significant magnitudes of correlation for previous year's fall (r=-0.35 with LW_a), previous year's wet season (r=0.37 with EW), and previous year's total annual precipitation (r=0.36 with EW) over total width measures, strengthening the case for use of these additional measures in reconstruction of seasonal precipitation patterns. These results suggest a clear partitioning of growth between early and latewood and the seasonality of rainfall in Mongolia. They confirm the ability of adjusted latewood widths of larch to capture early and late season precipitation signals in the Khangai.

These findings could be used for examining changes in the patterns of seasonal rainfall over several decades prior to the instrumented meteorological record depending on the length of measurable earlywood/latewood record. Correlations could also be made between remotely sensed, and other measurements of seasonal moisture patterns, such as timing of vegetative green-up and brown-down to corroborate and perhaps extend observations of these conditions into the past. At minimum, a determination of state of seasonal precipitation could be made, i.e. dry vs. wet spring or fall. Such a metric may provide insight into the severity and patterns of historical *dzud* (winter disaster and livestock death) through qualitative comparison to state (wet/dry) of seasonal patterns.

ACKNOWLEDGEMENTS

The authors would like to thank Tumenjargal Sukh for providing the precipitation data from the Mongolian Institute of Meteorology, Hydrology and the Environment (IMHE) used in this analysis, and the tree-core collection team of Dr. Steven Fassnacht, Odgarav Jigjsuren, and Sukhbataar Jaminkhuyag (team also included the second author, Venable). Biogeography lab facilities for core processing were provided by Dr. Jason Sibold of the Department of Anthropology at Colorado State University. We would also like to thank Dr. Peter Brown of Rocky Mountain Tree-Ring Research for his insight and advice regarding the core dating and analysis process. The collection of the tree-ring data was supported by the American Center for Mongolian Studies (ACMS) US-Mongolia Field Research Fellowship Program, and the National Science Foundation Dynamics of Coupled Natural and Human Systems Program (Award BCS-1011801 PI Dr. Maria Fernandez-Gimenez). The comments of two anonymous reviewers were greatly appreciated.

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Table 1. Significant correlations between tree-ring type (indices) and seasonal precipitation, where (c) and (p) indicate current and previous year's precipitation, and chronology statistics for each tree-ring type. Note: EPS quantifies how well a chronology (based on a finite number of trees) represents a hypothetically perfect chronology. RBAR is a measure of the average correlation between cores from one tree (RBAR within), between cores from different trees (RBAR between), and the effective signal from the chronology (RBAR effective).

		Total width	Earlywood width	Latewood width	Adjusted latewood
Seasonal Correlations	Spring (c)	--	--	--	-0.29
	Summer (p)	0.46	0.47	0.29	--
	Fall (p)	--	--	--	-0.35
	Wet (p)	0.36	0.37	--	--
	Dry (c)	--	--	-0.32	-0.34
	Total (p)	0.34	0.36	--	--
Chronology Statistics	EPS	0.86	0.85	0.81	--
	RBAR within	0.71	0.68	0.51	--
	RBAR between	0.42	0.40	0.32	--
	RBAR effective	0.50	0.48	0.42	--

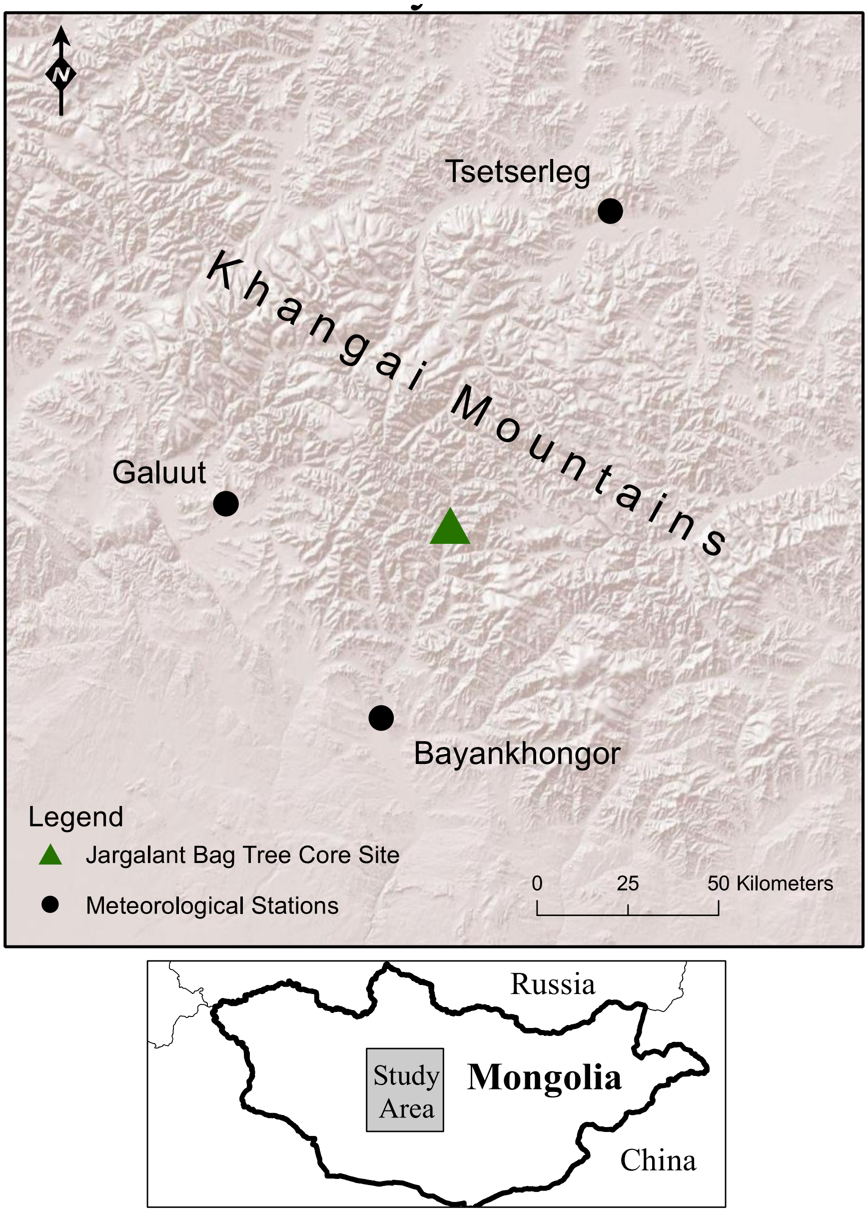

Figure 1. Tree-ring sampling site (triangle) and meteorological station locations (circles) in the Khangai Mountain region, Mongolia.