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Comparison Growth Situation of Tree-Ring Width between Poplars and Betula at the Floodplain Irtysh River, Altai, China

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ABSTRACT

Since the effect of soil moisture comparison of growth situation between Populus and Betula trees have not been studied, we choose it as our main objective. Tree-ring width chronology of Poplars and Betula was investigated on the Irtysh river floodplain, Altai Prefecture at an altitude of 500 m a.s.l. and climatic factors influencing the tree-ring width were examined. Why does soil moisture in different layers have unique relationships with our 3 sampling sites, when the conditions and altitude have slightly differences? Altai has a cold semi-arid climate, the sum annual rainfall is 202 mm and annual mean is 4.5°C. Mean expressed population signal in all 3 sampling sites was significant at 0.89. Three parameters of monthly climatic data [mean temperature, total of precipitation and soil moisture <<for 3 vertical layers (0.1-2.5 m)>>] were used for the analysis. Later formation rings of Betula platyphylla are related to soil moisture (0.495 at $p<0.01$) and precipitation (0.397 at $p<0.01$). Populus canescens growth was significantly influenced by July precipitation (0.337 at $p<0.01$). Populus euphratica is affected highly by soil moisture, which shows significant positive correlation from prior November to this May (0.485 at $p<0.01$) suggesting that tree rings integrate the state of the climate in the soil moisture. The results of this observation shows that better than regional hydroclimatic variability especially with soil moisture, Poplar gives way to Betula, because of stable and significant correlation, so Popular euphratica confirms that it is the best floodplains forest species for dendrochronological study.

Keywords: Tree-ring, Altai, Soil moisture, Poplar, Betula

INTRODUCTION

Annual growth rings of trees in various geographic regions have been shown in numerous studies over the past century to correlate with regional and local climatic variables measured by modern instruments, and provide one possible solution to the relative short–term nature of currently available stream flow data [1]. Correlations between the annual growth rings of trees and river discharge [2], while not resulting from a direct causal relationship, occur because trees incorporate the same climatic variables into their annual growth rings as does stream flow, including precipitation, evapotranspiration and soil infiltration.

Human activities directly influencing stream flow include water withdrawals for various purposes, losses due to evaporation in reservoirs, and water returns from groundwater extraction, amongst many others. While these estimates suffer from lack of precise data, especially concerning agricultural water withdrawals and returns, they are the best estimates of virgin flow available [3].

To prevent the disappearance of aquatic and coastal species and ecosystem services it is urgent to preserve existing, undamaged floodplains as a strategic global resource and begin to restore hydrological dynamics, sediment transfer and coastal vegetation to those rivers that maintain some level of ecological integrity [4].

The effect of hydrological changes on the growth of floodplain trees can vary depending on the topographic features in the floodplain due to differences in altitude, soil texture, drainage and soil moisture [4]. However, when flood conditions change by dams or levees, changes in vegetation, precipitation and nutrient handling change [5]. Hydrologic modifications can affect local surface and subsurface water levels, but water availability in the root zone is most important for floodplain tree growth [6].

There are several studies that have investigated the effect of dam operations and reconstructed stream flow on tree growth [7-9]. There are a few investigations in Altai Mountains of China like reconstructions of precipitation [10] and relative humidity [11], climatic response of tree-ring, which reveals recent warming trends, but relatively scarce studies observed in the floodplain of Altai Prefecture and especially effect of soil moisture and comparison of growth situation between Populus and Betula trees.

MATERIALS AND METHODS

Characteristics of study area

The study area is located (47°15’-48°22’N/86°19’-87°49’E) in the Altai Prefecture it is a part of Ili Kazakh Autonomous Prefecture, in far northern Xinjiang, China. Altai Prefecture lies on the Irtysh River (Figure 1). The Irtysh is the second biggest river in Xinjiang, which begins its current at an altitude of 2500 m above sea level from the slopes of the Mongolian Altai mountain system covered in snow and glaciers in Dzungaria and flows through China 633km in length (a geographical region in northern Xinjiang in northwest China) [12].

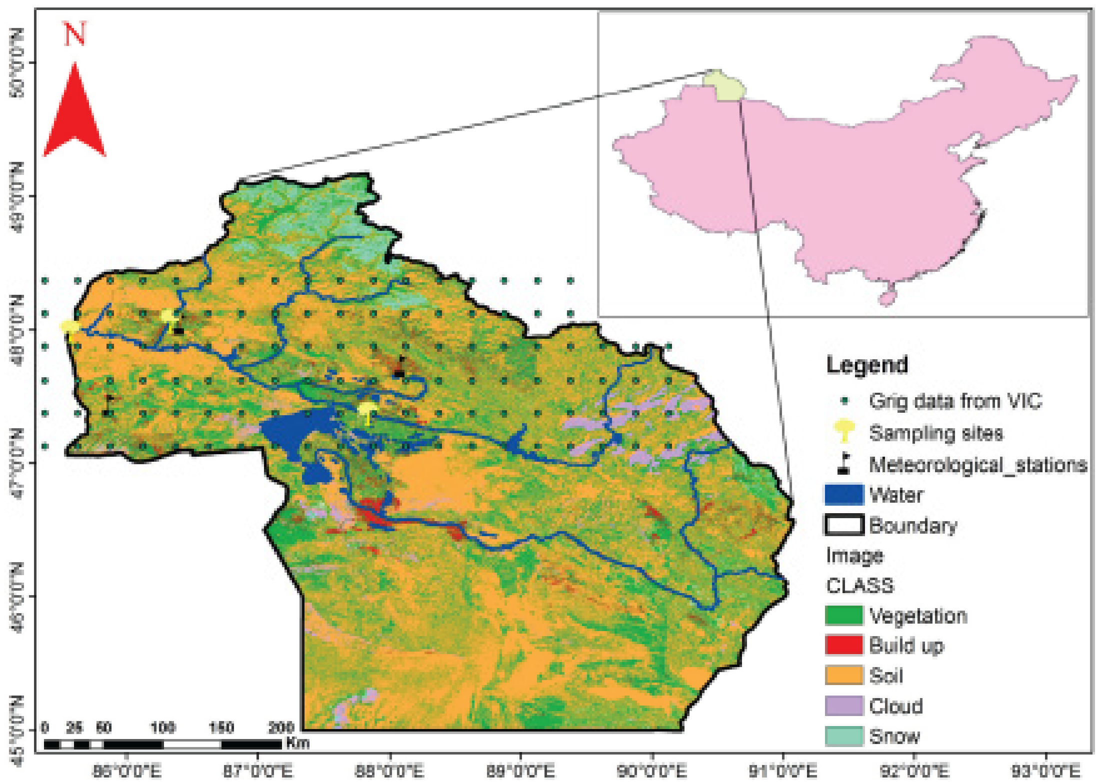

Figure 1: Location of study area in Altai Prefecture, China

Meteorological data was obtained from the vicinity of our sampling sites (Figure 2). Altai has a cold semi–arid climate, without a strong monsoonal influence on seasonal precipitation patterns that defines the climate across much of China. Based on averaged instrumental data from 3 stations in Altai over the common period of 1961-2015 the sum annual rainfall is 202 mm and annual mean is 4.5°C. Winters are long, bitterly cold and dry, with the coldest month in January of -14.5°C; however, the presence of the Altai Mountains to the north helps moderate the severity of winter cold as compared to locations further to the east. Spring and autumn are short but mild. Summers are dry and with the highest mean temperature in July was 21.6°C.

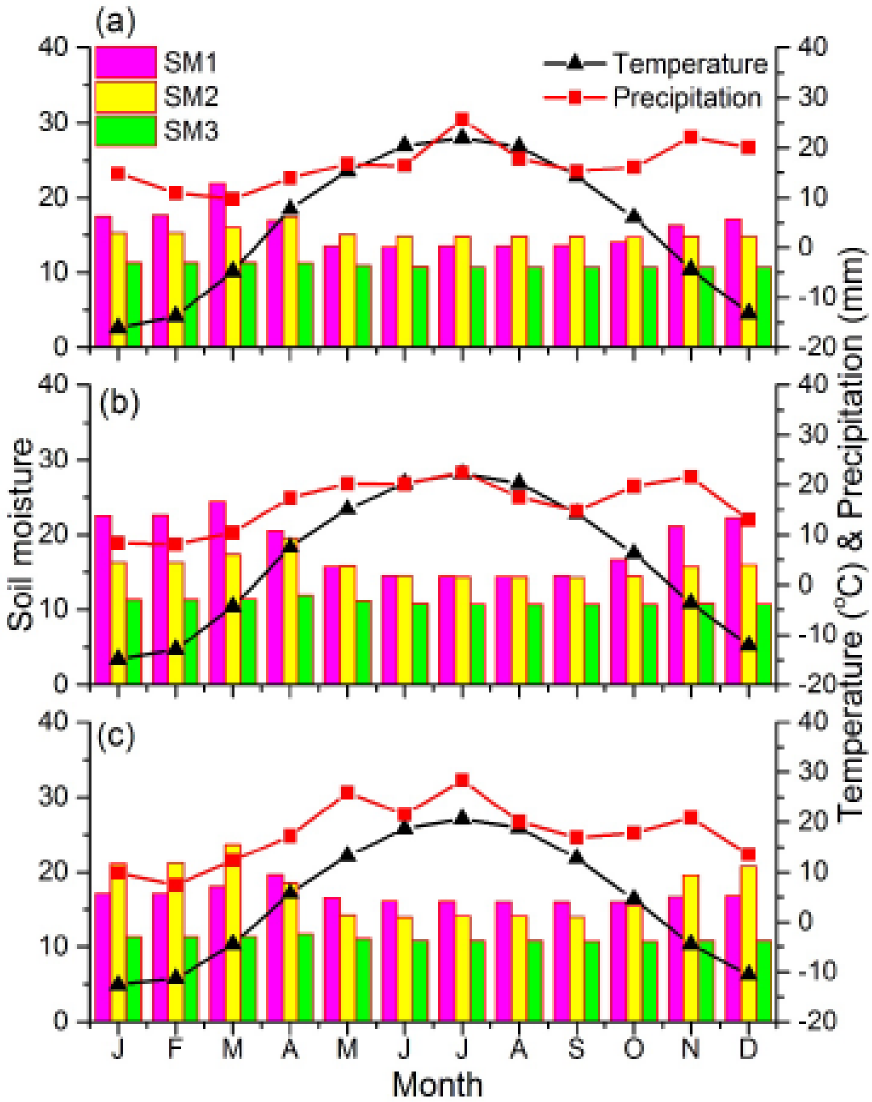

Figure 2: Climate diagram like precipitation and temperature from 3 meteorological stations vicinity to our sampling sites: (a) Altai; (b) Habahe; (c) Jimunai (Table 1). Soil moisture: (a) Beitun; (b) Habahe; (c) Ehedaqiao

Populus euphratica Olivier, Voy. Emp. Othoman 3: 449. 1807. Trees; trunk usually straight; bark furrowed or smooth, often gray or tan; pith mostly 5-angled in cross section. Floodplain forests, forming dense stands along riverbank of Irtysh that are likely clones formed from runners of a parent tree. In the Central Asia the most biologically productive, economic importance, great cultural, corresponding recreational, aesthetic values and diverse ecosystems are *Populus euphratica* Olivier floodplain forests. On the other hand they are a major natural resource for human populations; on the other hand they provide environmental benefits, such as landscape preservation, wind-breaks, sand fixation, and soil and riverbank protection [13].

Populus canescens (Aiton) Smith, Fl. Brit. 3: 1080. 1804. *Populus alba* Linnaeus var. *canescens* Aiton, Hort. Kew. 3: 405. 1789. Trees to 20 m tall, suckering freely; bark grayish or bluish gray, smooth, rough at base of trunk; crown spreading. Regarded by many authors as a hybrid between *Populus alba* and *P. tremula*.

Betula platyphylla Sukaczev, Trav. Mus. Bot. Acad. Imp. Sci. St.-Petersbourg. 8: 220. 1911. Trees to 30 m tall; bark grayish white, exfoliating in sheets. Temperate broad-leaved forests, shaded, S-facing slopes, ridges, dry, sunny slopes, marshes, forming vast, pure stands or mixed with Acer, Larix, Picea, Tilia and other species of Betula; 700-4200 m [14].

Sampling tree - Rings and chronology development

We choose Populus and Betula because it is the most common species in our study area and sampled at 3 sites located in the Altai County (Figure 1) encoded sites Beitun (BT), Habahe (HBH) and Ehedaqiao (EHD) (Table 1). According to the International Tree-Ring Data Bank [15] standard, two or three increment cores were taken from each tree. Beitun (BT) study area is located in the central part of Beitun city (47°22'N, 87°49'E, 495-520 m a.s.l.). *Populus euphratica* tree height ranged from 10 to 21 m depending on site conditions; the diameter ranged from 110 to 210 cm; alluvial (floodplain) soils predominate. Generally, two cores per tree were extracted with an increment borer. A total of 49 cores were taken from 25 trees.

Habahe (HBH) site is a Habahe county is under the administration of the Altai Prefecture. Floodplain generally covered by *Betula platyphylla* in an open stand in a highly human-disturbed environment. The sampling site (48°04'N, 86°19'E) was at 480–530m altitude a.s.l. Tree height ranged from 15 to 20 m in this location; the diameter ranged from 90 to 170 cm. A total of 37 cores from 19 trees were collected.

Ehedaqiao (EHD) (47°59'N, 85°33'E, 400-425 m a.s.l.) site also has floodplain soil which located on the border with Kazakhstan. *Populus canescens* tree height ranged from 10 to 15 m in this sampling site; the diameter ranged from 90 to 130 cm. A total of 47 cores were sampling from 25 trees.

In the laboratory, the increment core samples were air–dried, mounted on a wooden mounts, grinded and polished with sandpaper (400-1200 grit cm^{-2} for better-identified fall rings) until tree-ring boundaries were visible under a microscope. The tree-ring width series from three sites were cross-dated visually [16]. Than ring width were measured to 0.001 mm precision with a LINTABTM–6 tree ring analyzer (Germany) with TSAP-Win Professional software [17]. Statistical cross–dating was performed with COFECHA program (http://web.utk.edu/~grissino/software.htm, Version 6.06P) and only tree-ring series that fell within a 99% confidence interval of the stand average using Pearson's correlation (critical correlation of 0.42) were kept for the chronology [18]. The cross-dated tree-ring widths were detrended and indexed using ARSTAN software [19]. To evaluate the reliability of the chronology the length in years of segment to examine 30 years lagged by 15 years were calculated: average growth rate (AGR), mean correlation (MC), mean sensitivity (MS), signal-to-noise ratio (SNR), standard deviation (SD), 1st order autocorrelation, inter-series correlation (Rbar), the subsample signal strength (SSS) and the expressed population signal (EPS). The EPS determines how good a chronology established on a finite number of trees approximates the theoretical population chronology and the SSS statistics was used to determine the minimum number of trees that should be used to reliable estimate of the mean chronology [20].

Meteorological data and statistical analysis

Bootstrapped correlation functions between standard chronology and the climate data were computed by SPSS software. Since the climate stations showed lower correlations with the tree–ring data than the gridded records, and because it provides a more regional signal than the station records away from all our study area. The hydrologic dataset covers China with a 0.25° spatial resolution and a daily time step for 1952-2012 monthly soil moisture kg m^{-2} for 3 vertical layers within 2.5 m soil depth (i.e., 0.1m, the 2nd and 3rd layers vary within the range of 0.1-2.5 m) were obtained from the http://hydro.igsnrr.ac.cn/ [21] interpolated for the sampling site (Table 1) by using MATLAB [22].

Table 1: Characteristics about the sampling sites and vicinity meteorological station

Site	Tree species	Lat. (N)	Lon. (E)	Core/tree number	Altitude (m)	Characteristic of meteorological stations				
						Station	Lat. (N)	Lon. (E)	Altitude (m)	Time span (year)
BT	*Populus euphratica*	47°22'	87°49'	49/25	508–516	Altai	47°44	88°05	7353	1957-2015
HBH	*Betula platyphylla*	48°04'	86°19'	37/19	480–530	Habahe	48°03	86°24	5326	1958-2015
EHD	*Populus canescens*	47°59'	85°33'	47/25	400–425	Jimunai	47°26	85°52	9841	1961-2015

RESULTS

Width chronologies and climatic signals

Figure 3 shows the tree–ring width chronologies. The longest record for the Altai Prefecture is 84 years from EHD site and shortest 69 years from HBH site. A summary of the standardized chronologies is given in Table 2. High mean correlation (0.56 and 0.63) with master series indicates good cross-matching between the sequences and shows the common signal between the series. In contrast, the chronology in BT has the lowest 1st order autocorrelation (-0.201), indicating high levels of year-to-year variation. The inter-annual measure variation of mean sensitivity ranges from (0.281 and 0.282), which suggesting that the Poplars are slightly sensitive to environmental variability [23]. The chronologies had high EPS (expressed population signal) (0.88 and 0.91), high SNR (signal-to-noise ratio) (7.3 and 10.2) and high standard deviation (0.222 and 0.253) indicating that the radial growth of trees was responding to common factors and was suitable for dendroclimatic research. Variance explained by the 1st principal component accounted for 45-55% indicating that rather moderate common signals exist among trees.

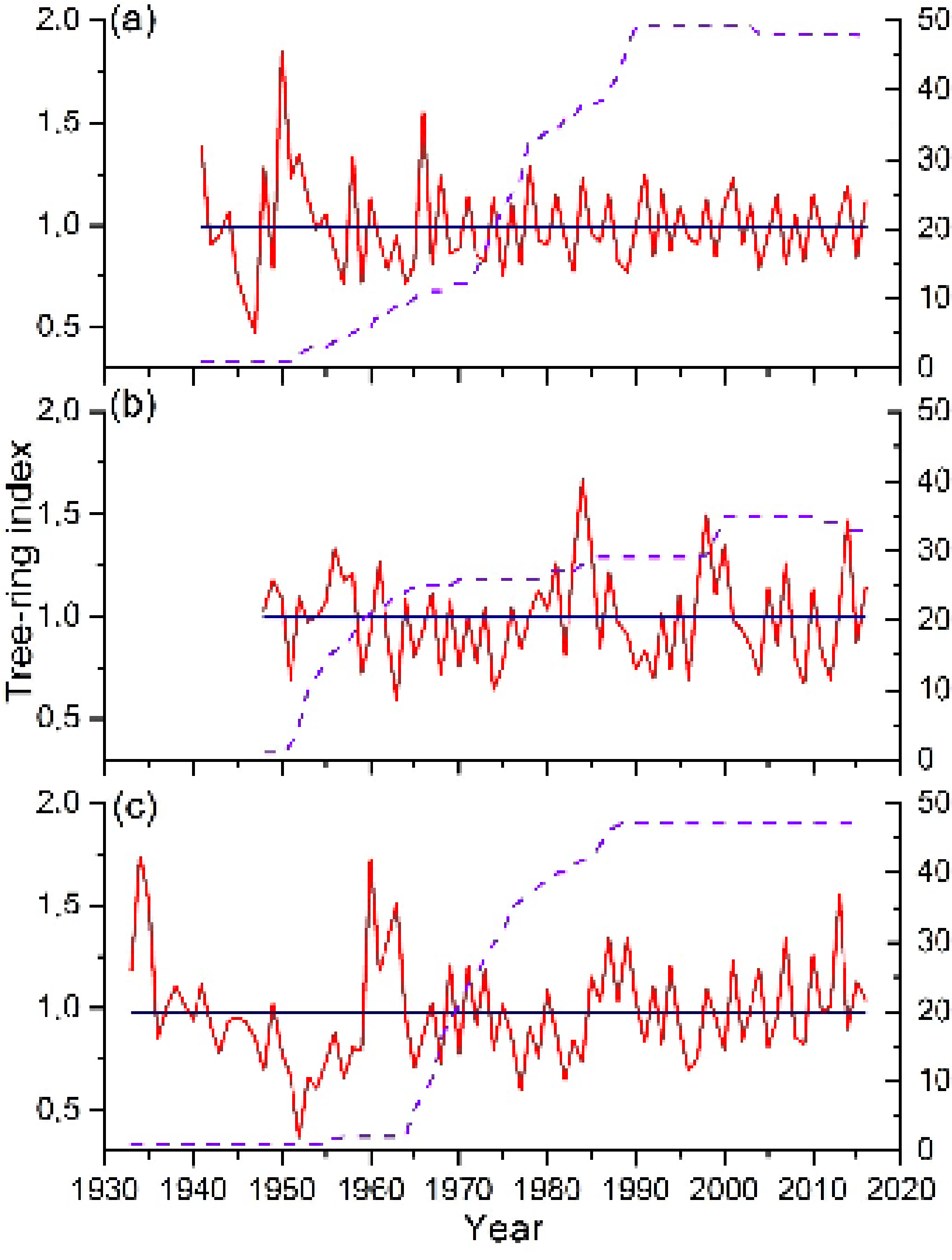

Figure 3: Standardized tree-ring-width chronology and sample depth of *Populus euphratica* at the floodplain on Altai prefecture in Xinjiang, China. (a) BT; (b) HBH; (c) EHD

The chronology of the BT site correlates negatively with April temperature mean of the current growing season, significantly positive correlated (at $p<0.01$) with this January-March (0.318 at $p<0.05$) precipitation. Ring width at EHD site is also negatively correlated with temperature mean in prior October and this June, with precipitation negatively correlated in prior June, but positively this July (0.337 at $p<0.01$). Chronology from HBH site positively correlated with temperature mean in priors May and August, and negatively with current June, significantly positive correlations were found with precipitation (0.397 at $p<0.01$) in this May-June and negatively prior June.

Table 2: Summary of statistics for standardized chronologies of *Populus euphratica*

	Chronology		
	BT	**HBH**	**EHD**
No of trees (tree/core)	25/49	18/35	25/47
Chronology period	1941-2016	1948-2016	1933-2016
Length (year)	76	69	84
Mean (1/100 mm)	467.4	308.6	277.7
Mean sensitivity(a)	0.281	0.282	0.266
Standard deviation(a)	0.222	0.236	0.253
AC1(a)	-0.201	0.176	0.253
AC1(b)	-0.249	-0.140	-0.037
MC(c)	0.56	0.65	0.63
MSL(d)	41.7	50.7	44.7
R(e)	0.422	0.506	0.439
PC#1(f)	47.85%	54.64%	45.35%
SNR(j)	7.3	10.2	7.8
EPS(k)	0.88	0.91	0.89
SSS(l) [year (n)]	1965 (6)	1953 (7)	1967 (7)

(a) From standardized data series; (b) From residual data series; (c) Mean correlation with master series; (d) Mean segment length; (e) All series *Rbar*; (f) Variance explained by the first principal component; (j) Signal-to-noise ratio; (k) Expressed population signal; (l) Subsample signal strength

The results of correlation functions analysis showed that the summer precipitations had positive effects on tree growth, while temperature mean had negative effect on the current growth year and positively influence on the prior growth. However, we are thinking that the growth of ring width in this region is not solely controlled by temperature or precipitation. Therefore, to investigate the climate tree–ring relationships, we screened the tree-ring chronologies in correlation analysis with the 3 layers of soil moisture, temperature mean and total precipitation (Figure 3). We found strong positive correlations between the BT site and soil moisture 1st layer from prior November to current May (0.485 at $p<0.01$), but negatively correlated with this November; with HBH site there only correlation in prior July (negatively) and current June (0.495 at $p<0.01$) (positively). With soil moisture 2nd layer with BT site positively correlation from January to May (0.332 at $p<0.01$). EHD site negative correlations were found in the prior April-May and August and this year January-March. Positive correlations between soil moisture 3rd layer and BT site were observed in current January-June (0.280 at $p<0.05$). EHD site, was negatively correlated with prior April and current January-April. All the above correlations not mentioned in which level are significant at the $p<0.05$ in two-tailed tests.

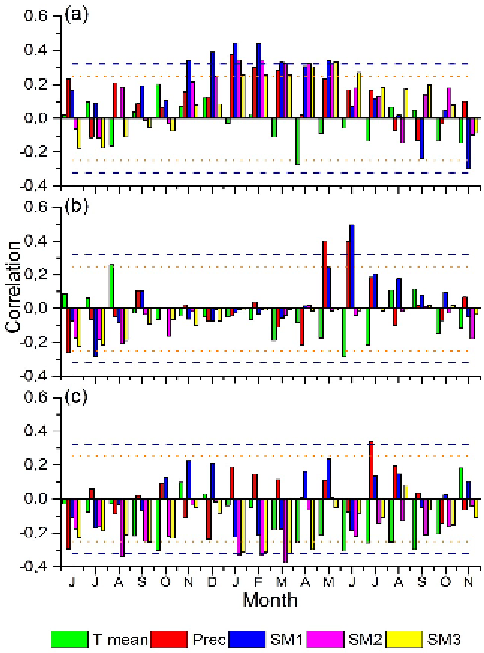

Figure 4: Correlation coefficients (bars) between tree-ring chronology and climatic data (a) BT; (b) HBH; (c) EHD. The horizontal dashed lines indicate the $p<0.01$ and dotted lines indicate the $p<0.05$ significance level for the correlation function

However, these positive correlations of soil moisture seem to depend on precipitation due to the same precipitation ratio with soil moisture since the beginning of the growing season, with the exception of the temperature of its influence, so far they have not been studied. Correlations between tree-ring width and soil moisture were as high as or higher than for precipitation or temperature alone, suggesting that tree rings integrate a set of climate in the soil moisture. Why does soil moisture in different layers have unique relationships with our 3 sampling sites, when the condition and altitude have slight differences?

DISCUSSION

The correlation analysis showed that ring width in all the sampling sites was negatively correlated with prior October, current April and June temperature mean, and with June precipitation prior growth, negative correlations have also been found with soil moisture in different layers with prior April-May, July-August and this January-April and November.

As shown in Figure 2, the maximum temperature corresponds to the maximum precipitation, and the minimum temperature to the minimum precipitation, that is to say, the higher the temperature is in the growth season, the more intensive the soil evaporations and plant transpirations are and this leads to worse conditions for tree growth, which has very little effect on the growth of trees, since it almost does not remain in the soils [24].

In addition to the role of soil moisture in the interactions between the land surface and the atmosphere, soil moisture is a storage of water between rainfall and evaporation that acts as a regulator to one of the more fundamental hydrologic processes, infiltration and runoff production from rainfall and which must be accounted for in any water and energy balances [25]. As we can observed in (Figure 2) soil moisture of 1st layer is higher than other layers so that's why correlation between 1st layer of soil moisture and tree-ring width is significant.

The roots of Betula the same as Poplars are on the surface of the earth and contribute to the retention of water in the deep layers, as the roots of these kind of trees constantly need moisture, the roots simply pull out moisture and nutrients from anywhere, that is why so few other representatives of the plant kingdom grow around them. Therefore, in the Figure 4b we can observe the positive correlations between ring width of *Betula platyphylla* and climatic conditions like precipitation and 1st layer of soil moisture have significance at $p<0.01$, we assume this is due to increased precipitation and an increase in soil moisture.

There are several investigations that a major climatic factor enhancing tree growth at low dry altitudes was summer precipitation, but at high altitudes in boreal forests and in subalpine forests it was summer temperatures [26]. As [27] mentioned temperatures influence tree growth in several ways: as photosynthetic rates of plants are generally temperature dependent, so low temperatures during the growing season reduce photosynthetic production [23]; positive correlations were estimated in the early summer temperatures in the current years, by prolonging the duration of the growing season [28]. Opposite view of this were shown in this study at HBH site because of the positive correlation of the tree-ring width with prior temperature mean, and negatively correlated with this June. It is believed that the growth of *Betula platyphylla* strongly depends on the prior year's photosynthetic production. Therefore, the growth of *Betula platyphylla* is apt to be affected by the prior year's climatic conditions, and soil moisture of later formation rings (May and June) and June precipitation. At EHD site generally negative correlations were found between *Populus canescens* ring width and climate conditions, except precipitation of this July, which has great influence on the formation of the width of the rings, during the hottest period, which is associated with a possible deficit of water. We believe, the growth of *Populus canescens* is influenced by another climate factors as: stream flow, insolation duration or base flow. With certainty, we can say that in BT site *Populus euphratica* growth is controlled by soil moisture from the very beginning of its growth, since we found correlations from last year November to present May. Precipitation is greater at these sites, which is associated with increases in air temperature and high levels of evaporation (Figure 2). In addition, all of our study area lies in the Irtysh River. Such local-scale climatic conditions would hardly cause water stress for floodplain forest, but would reduce moisture of the soil.

CONCLUSION

Poplars and Betula were successfully cross-dated and dendrochronologically analysed in Altai Prefecture. During the study, a different manifestation of the growth and development of these trees was studied, in which individual indices for the influence of external climatic influences.

a) *Betula platyphylla* strongly depends on the prior year's photosynthetic production and later formation rings is related to soil moisture and precipitation.

b) *Populus canescens* growth is significantly influenced by July precipitation and other climate factors; we propose stream flow, insolation duration or base flow.

c) *Populus euphratica* is under effect of soil moisture.

The results of these observations show that greater regional soil moisture hydroclimatic variability Poplar gives way to Betula, because of stable and significant correlation, so popular euphratica confirms that it is the best floodplain forest species.

• The water availability in winter and late spring is the main limitation to radial growth.

• The chronology is strongly correlated with soil moisture and suggests that the most important factor for growth of floodplain forest is the storage of water in the soil. For a better understanding of climate relations, growth and the difference in climatic signal, further research is needed on the different heights and exposures, as well as other parameters of the tree ring (early and late wood widths), other parameters of instrumental data (stream flow, insolation duration or base flow) in order to make full use of the potential, of climate variability in this key area.

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