Pak. J. Bot., 52(2): 593-600, 2020. DOI: http://dx.doi.org/10.30848/PJB2020-2(16)

CLIMATE GROWTH RESPONSE OF *PINUS SIBIRICA* (SIBERIAN PINE) IN THE ALTAI MOUNTAINS, NORTHWESTERN CHINA

SHER SHAH[1], JIAN YU[1], QIJING LIU[1*], JINGNING SHI[1], ADNAN AHMAD[1], DILAWAR KHAN[1] AND ABDUL MANNAN[2]

[1]*Laboratory of Integrated forest analysis, College of Forestry, Beijing Forestry University, Tsinghua East Road No. 35, Haidian District, Beijing 100083, China*
[2]*Beijing Key Laboratory of Precision Forestry, College of Forestry, Beijing Forestry University, Tsinghua East Road No. 35, Haidian District, Beijing 100083, China.*
[*]*Corresponding author's email: liuqijing@bjfu.edu.cn; Tel.: +86-1062338133*

Abstract

The Altai Mountains in Northwest China has a great potential for dendroclimatological studies. Dendrochronological and climatological response analysis potentials of the northwest China Altai Mountains are hitherto unexplored. In this study, for the first time we have developed chronology statistics and climate response growth analysis of *Pinus sibirica* using (dplR) and (Treeclim) packages of the R program, with the overall goal of documenting baseline information for future research. The chronology covered a span of up to 202 years in the study site. The results highlighted that the chronology showed highly significant negative correlation to the previous year June and highly positive significant correlation to the late winter March maximum, minimum and average temperature respectively. The results further revealed negative responses for the previous year March in term of Palmer Drought Severity Index (PDSI) value (-0.027) but positive PDSI values (0.035, 0.014, 0.027) for April, May, and June. The results indicate that tree ring widths are not responding positively to the previous year growing season at the current chronologies of 202 years. These findings suggest more extensive research on the climate-growth reconstruction and Response Function Analysis of the trees for longer chronologies up to their natural age of 800 years.

Key words: Dendroclimatology, Response function analysis, Siberian pine (*Pinus sibirica*).

Introduction

Dendroclimatology provides information through statistical procedures about the past climatic changes especially decadal, centennial, and interannual scales (Briffa *et al*., 1998b). The tree ring data provides annually resolved histories of the tree growth that are proxies for the past climatic variation (Fritts, 1976) such as, volcano and drought, etc. The climate-growth relationship underlines the effect of climate on tree ring widths over a long period. Apart from climatic factors, other factors such as slope, exposure, soil moisture, O^3, UV-B levels, and tree species associations also affect the tree ring widths (Sidorova *et al*., 2012). The challenge for the dendrochronologists is to reconstruct and represent the past climate variability of a particular factor.

In dendroclimatological studies, careful selection of a suitable site for tree ring sampling is important to maximize the potential climatic sensitivity within the sampled tree rings. The temporal stability will be biased if the data is collected from trees of different ages. Younger trees have wider and denser rings than older trees (Fritts, 1976; Schweingruber *et al*., 1988), while older trees have significant climatic variance and climate responses (Büntgen *et al*., 2009). In multi-aged forests, the climate-growth relationship and climatic reconstructions can have a bias, because at different times the chronology respond differently to their size and age (Szeicz & MacDonald, 1994; Szeicz & MacDonald, 1995). In temperate climate zones, the trees and shrubs growth stops during the winter and the tree rings are mostly formed during the growing season (Fritts, 1976). Drought is one of the most important and long-lasting natural disasters on forests and other sectors like agriculture etc. due to its long duration and limited predictability (Mishra & Singh, 2010). In many parts of the world, the Palmer Drought Severity Index (PDSI) used as a tool for measuring the severity of drought (Lloyd Hughes & Saunders, 2002; Ntale & Gan, 2003; Dos Santos & Pereira, 1999).

The Altai Mountains ranges are located in Central Asia, where the junction of China, Mongolia, Russian, and Kazakhstan occurs. In China, the northwest part of this mountain range located at 52°N, 80°-90° E where its south to 46° N, and gradually its elevation becomes lower and merges into the Gobi desert plateaus. The Altai mountain range is covered by widespread coniferous forests and has a high potential for tree ring studies. The elevation in the Chinese Altai ranges from 3115 m to 1315 m in the lower plateaus of the Gobi desert. The Chinese Altai is characterized by a temperate arid climate, with westerly and northerly winds from the Arctic and Siberia (Chen *et al*., 2017). The mean annual temperature is 4.9°C, where June and July are the hottest and wettest months, and annual precipitation 189 mm (https://crudata.uea.ac.uk/cru/data/crutem/ge). The coniferous forests are dominated by *Picea obovata* along with *Larix sibirica*, *Picea sibirica*, *Pinus sibirica* and *Abies sibirica*. The *Pinus sibirica* tolerates the extreme cold temperate and dry continental climate characteristic of western Siberia, Russia, and northern Mongolia (Alton *et al.*, 2005; Tchebakova *et al*., 1994; Politov *et al*., 1999). Dendroclimatic studies for *Pinus sibirica* are rare and very few studies have been conducted in western Siberia, eastern Siberia, and northern Mongolia but not a single study has been conducted on Siberian pine inside the Chinese Altai. At Makhrino peat land in western Siberia, the *Pinus sibirica* chronology reaches to minimum ages of 536 and 526 years (Blanchet *et al*., 2017) it shows a highly significant negative relation to the trees growing on the peat soil with that growing on mineral soil (saline soil).

Various studies have been carried out in Altai Mountains on other species such as *Larix sibirica* in the Russian Altai (Taynik *et al*., 2016), the Altai Sayan Mountains (Ovchinnikov & Vaganov, 1999), the Aktru valley Altai (Ovtchinnikov *et al*., 2000) and the Kurari ridge. Oidupaa conducted two studies on three different sites and developed Tree Ring Width (TRW) chronologies of 1103, 583, and 421 years long for *Larix sibirica* (Oidupaa *et al*., 2011). 1241 years of TRW chronology was developed by (Nazarov & Myglan, 2012) for *Pinus sibirica* in the valleys of Aktru, Korumdu, Maashei in the Altai Sayan Mountains of Russia, in Mongolian Altai and Ural Mountains (D'Arrigo *et al*., 2000). Narrow rings in *Pinus sibirica* indicated cooler conditions from the early 1700s, followed by warmer temperatures in the mid and late 1700s.

Few studies are available on precipitation and temperature reconstruction for the Altai Mountains of northwestern China. However, the current number of tree ring chronologies for the Chinese Altai Mountains is insufficient for climatic reconstruction. Only a few individual continuous tree ring series have been constructed for *Larix sibirica* for a period of (212 and 373) years (Chen *et al*., 2014). However, until now, there has been no information on the Siberian pine inside the Chinese Altai, Xinjiang region. Due to extreme cold and stress weather (low temperatures and low precipitation) in the Altai Mountains, the study of *Pinus sibirica* will give us the knowledge about past climate through ring width reconstruction. Long term records regarding climate are necessary to observe the development of the climate and also track back the environmental impacts on Siberian pine tree rings. The present study for the first time explored the chronology of the Siberian pine in order to figure out (Briffa *et al*., 1998a) the relationship between the climatic factors (PDSI, precipitation, annual maximum, minimum, and average temperature) (Fritts, 1976) and to study the response of the previous growing season on the current year tree ring width growth.

We hypothesize that the low mean sensitivity resulted from ARSTAN standardization, shows that climate does not affect the tree ring growth. The standard for mean sensitivity is 0.2 to 0.3, which tells us that climate significantly affected the tree ring growth. The mean sensitivity, exceeding than 0.2 considered as not valid for performing climatic reconstructions (Fritts, 1976; Ntale & Gan, 2003). The objective of the study was to find growing season effect on the current year tree ring width of the *Pinus sibirica* using 202-year chronology.

Materials and Methods

Study site: The Altai Mountains range lies at the junction of the Northwester China, Altai Republic Russia, East Kazakhstan and Northwestern Mongolia. A wide range of elevation occurs at the Altai Mountains where it reaches to 1573 m a.s.l., at the lower bottom and gain a height of 2310 m a.s.l., at the snow covered mountains of China Russia and East Kazakhstan border (Fig. 1). The Altai Mountains experience a semi-arid continental climate. The mean annual temperature from 1901 to 2016 ranged from -2 to – 5.6˚C, January was the coldest month with a mean temperature of – 22˚C, while July found to be the warmest time of year averaging 13˚C. The mean annual precipitation ranged from 173.2mm to 534.7mm, most of which occurred in the three months of the summer (June, July, and August) (Fig. 2). Monthly instrumental data were taken from the nearest meteorological stations of Habahe (48.05N, 86.40E, 500 m a.s.l., 1958-2016 for temperature and 1958-1990 for precipitation); Orlovkiy Poselok (48.70N 86.48E, 1081 m a.s.l., Precipitation 1958-1993); and Katon Karagay (49.70N 86.50E, 1800 m a.s.l.,1967-1993 for precipitation and 1940-2015 for temperature). The meteorological stations are located at 30km, 107km, and 83 km for Orlovskiy Poselok (KZ), Katun (RS) and Habahe (China) respectively (http://crudata.uea.ac.uk/cru/data/crutem/ge). Gridded CRUTEM4 (grid box 0.5° x 0.5°) data obtained from http://climexp.knmi.nl, to increase the instrumental period from 1901-2016 (Yu *et al*., 2017). *Pinus sibirica* found to be the dominant forest tree species growing along with *Abies sibirica* and *Picea sibirica*.

Tree-ring sampling and chronology development: The tree ring cores analyzed in this study were collected from three different sites (48.773450°N 86.869297°E, 48.682979°N 86.810688°E, 48.696511°N 86.864855°N) near the Kanas water lake with the aim of reconstructing the past climate using several tree ring proxies. The cores were collected from the *Pinus sibirica* growing at the Altai Mountains facing the northwestern and northeastern slopes with rocky soils surrounded by subalpine meadows, located at an elevation ranges from 1450 m- 1950 m (Myglan & Vaganov, 2012; Sidorova *et al*., 2012). In general, a single core was extracted from each tree at breast height (1.3 m above ground). An increment borer of 16″ to 32″ sizes were used for taking tree core samples. The cores were sampled in a direction parallel to the slop to avoid the influence of wood reaction.

Tree sample cores were brought to the laboratory and were air-dried before mounting and sanding. Using LINTAB^{TM} 6.0 measuring system, all the ring widths were measured with a 0.01mm precision (Stokes & Smiley, 1968). The accuracy of the cross-dating and width measurement was verified by using COFECHA (Holmes, 1983). Standard Chronology (Fig. 3) was developed using ARSTAN software (Cook *et al*., 1990). A well crossdated chronology can have an intercorrelation of at least 0.5; ours was 0.501 (Table 1) and therefore deemed acceptable. As our focus was to correlate climate with the tree growth, for that purpose the mean sensitivity should be at least (0.2 - 0.3) (2016), but in this study the mean sensitivity was 0.1064, showing the trees were responding poorly to climate. Additionally, Chronology quality was assessed using mean sensitivity (MS), standard deviation (SD), first-order autocorrelation (ACI), expressed population signal (EPS) and signal-to-noise ratio (SNR) (Yu *et al*., 2018).

Table 1. Summary statistics for the *Pinus sibirica* TRW chronology.

Specie	*Pinus sibirica*
Tree Cores	63
Time Span	202 years
Mean sensitivity	0.1034
Standard deviation	0.1356
Signal-to-noise ratio	0.459
Series intercorrelation	0.582

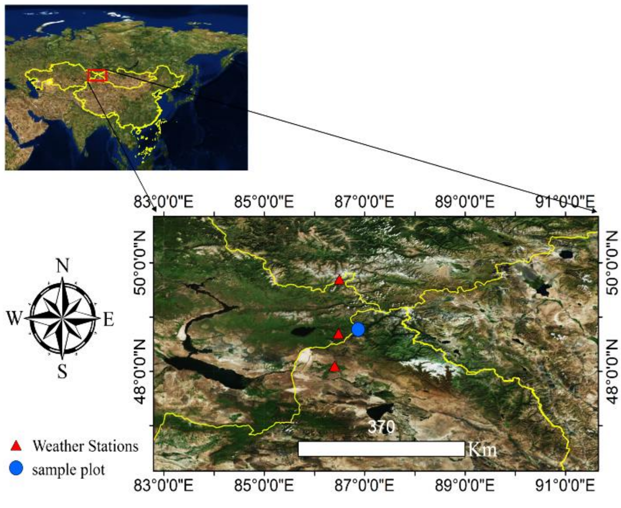

Fig. 1. Location of the sampling site (sampling plot), weather stations Habahe (China), Orlovskiy Poselok (KZ) and Katun (RS) and some tree rings data taken from ITRDB (International Tree Ring Data Base) for comparison.

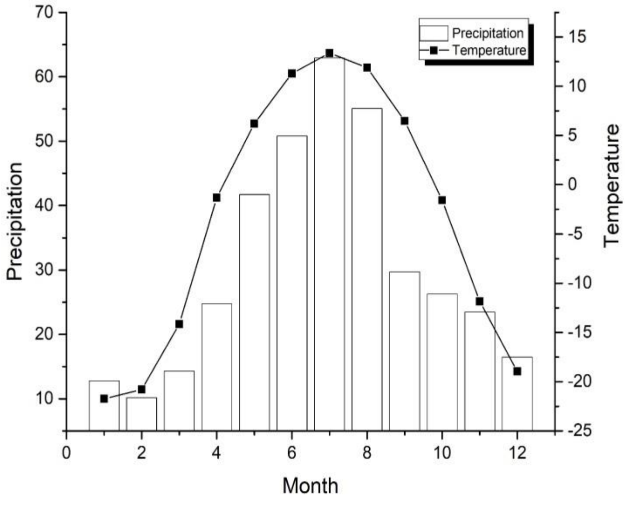

Fig. 2. Climograph for the showing mean precipitation and mean temperature over the last century (https://crudata.uea.ac.uk/cru/data/crutem/ge).

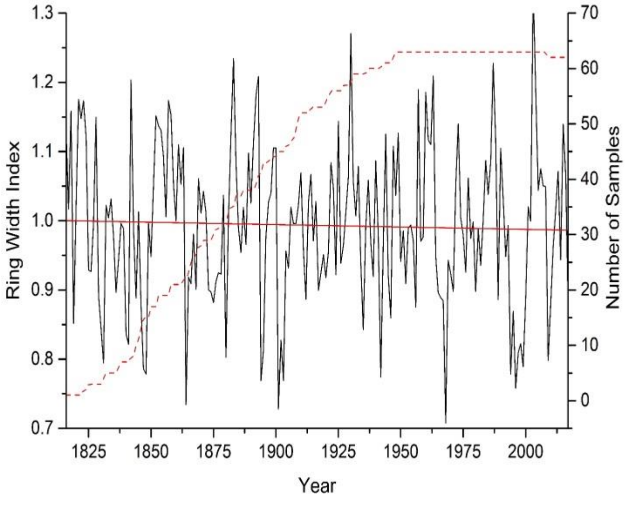

Fig. 3. Standard chronology of the *Pinus sibirica* from 2017-1816 and number of sample cores.

Climate growth relationship: The temperature, precipitation, and PDSI on the inter-annual variability of the tree ring growth were measured by the strength of the common signal. Climatic signals were measured through the correlation between the detrended chronologies and the monthly climatic data from the nearby meteorological station. The bootstrapping correlation coefficients method used by (Cook *et al*., 1990), including March (early start of the growing season) from the previous year to the September of the current year. The dlpR and Treeclim packages of the R program 3.4.3 was used, where dplR (Dendrochronology Program Library in R) used for performing some standard tree ring analyses and Treeclim (which calculates response and correlation functions from tree-ring chronologies and monthly climatic data), to visually represent the relationship between the tree ring width series and different climatic variables. Linear regression was used to find the relation of the average march with the minimum and maximum march, and Average June with minimum and maximum June temperatures (r^2 = 0.96, r^2 = 0.88, r^2 = 0.81, r^2 = 0.904) respectively. Response Function Analysis Graphs were created to verify their accuracy.

Results

Tree growth-climate relationships: Correlation coefficients are shown in between standard chronology and climatic factors from 1901 to 2016. The tree ring width chronology is showing a significant positive relation to the previous year April precipitation and significantly negatively relate to the September precipitation. Moreover, the tree ring width chronology was positively correlated with the previous year late September and a current year late winter (March) maximum temperatures, while negatively correlated to the July maximum temperature of the previous year. Similar patterns of the significant and non-significant values were observed between ring width chronology and maximum temperature for minimum and mean temperatures. No significant correlation was found between tree width chronology and PDSI. The highest correlation was identified between tree width chronology and mean temperature in March of the current year (r = 0.166, p<0.02), suggesting that the March mean temperature had a significant effect on the tree growth.

Response function analysis: The Response Function Analysis graphs produced with Treeclim highlighted the relationship between climate variables and annual tree ring growth from March through September of the following year. (Fig. 4) shows the relationship between precipitation and tree ring growth. The graph was generated by the Treeclim package within program R. The x-axis shows the March of the previous year through September of the current year of growth. The y-axis shows response functions indicating the relationships between the climate variables and ring width growth. When both ends of the line are above zero, it indicates a significantly positive relationship, and when both the ends are below the zero, it indicates a significantly negative relationship. There is a significant positive relationship found between previous year May precipitation and tree ring growth. There is a significant negative correlation among the previous year September (late summer) on the tree ring width due to low precipitation occurred in late September after long summer. A positive relationship was found among the previous year spring (April and May) precipitation with tree ring width. The summer June, July precipitations showing no close correlation with the tree ring width. The late summer precipitation shows a negative response to the tree ring width.

A significant positive correlation between the tree ring width (Fig. 5) and a current year late winter (March) minimum temperature, while also showing significant negative correlation to the current year July minimum temperature. This indicates that tree ring growth is positively responding to the late winter minimum temperature while negatively responding to the July minimum temperature. The growing season of the previous season has no as such effect on the current year tree ring growth while Tree ring growth is responding positively to the previous year August and September minimum temperature.

The tree ring growth had a significantly positive relationship to the current year March and previous September maximum temperatures (Fig. 6). The tree rings showed a significantly negative correlation to the July temperature. The previous year growing season did not show the same effect on the next year tree ring growth. The Response Function Analysis indicates that the tree ring growth positively responded to the previous year late summer and a current year late winter maximum temperature while responding negatively to the previous year July temperature. The (Fig. 7) shows the Response Function Analysis between the tree ring growth and Mean Temperature. The graph shows that the mean temperature responded the same ($r^2 = 0.87$) as a minimum temperature, showing a significant positive correlation between the tree ring growth and a current year later winter March temperature. The tree ring growth responded negatively to the current year July mean temperature indicates that Siberian pine is not surviving well in high temperatures.

In (Fig. 8) the higher scale shows higher precipitation periods and a lower number indicates the drier years for the Palmer Drought Severity Index (PDSI). The graph shows some strong positive correlation between Tree Ring growth and PDSI in the last year growing season. The PDSI and tree ring width responding positively to each other at the start of the spring in the previous year and decline to negative as the summer moves on and at late winter it shows positive relationship again. This negative decline and again showing positive relationships indicates that tree ring growth is responding positively to the winter while negatively to the summer.

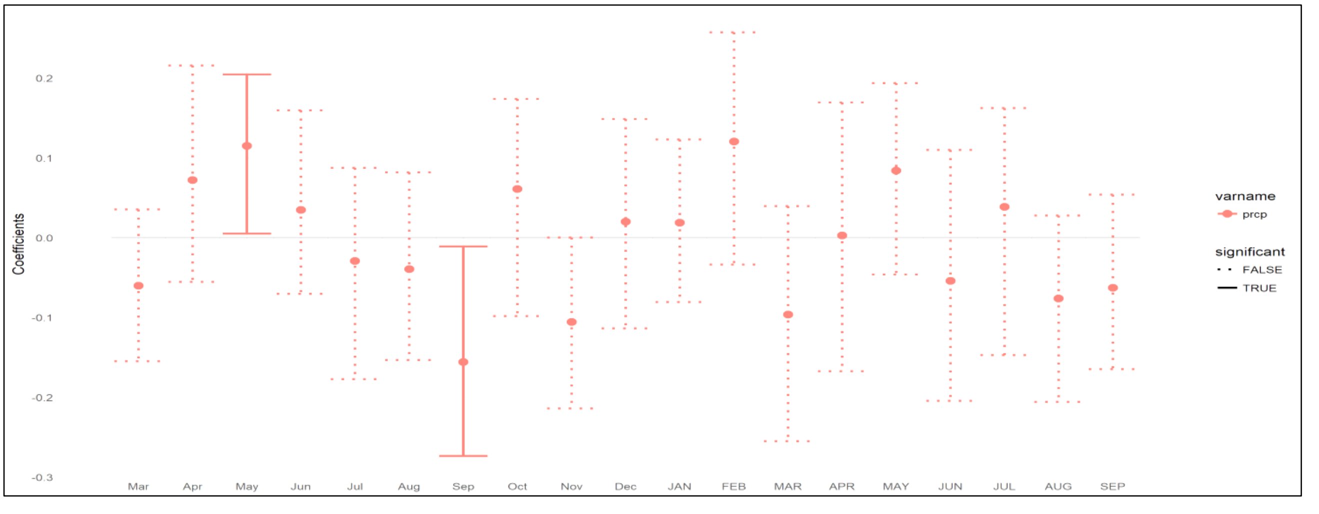

Fig. 4. Response function analysis graph of precipitation and tree ring growth.

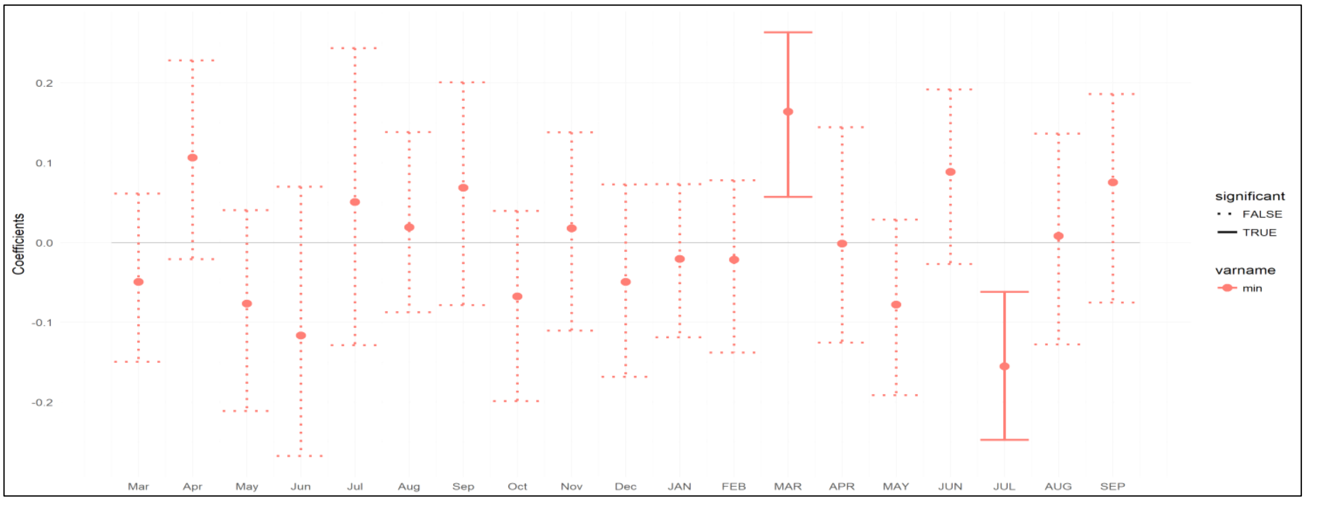

Fig. 5. Response function analysis graph of minimum temperature and tree ring growth.

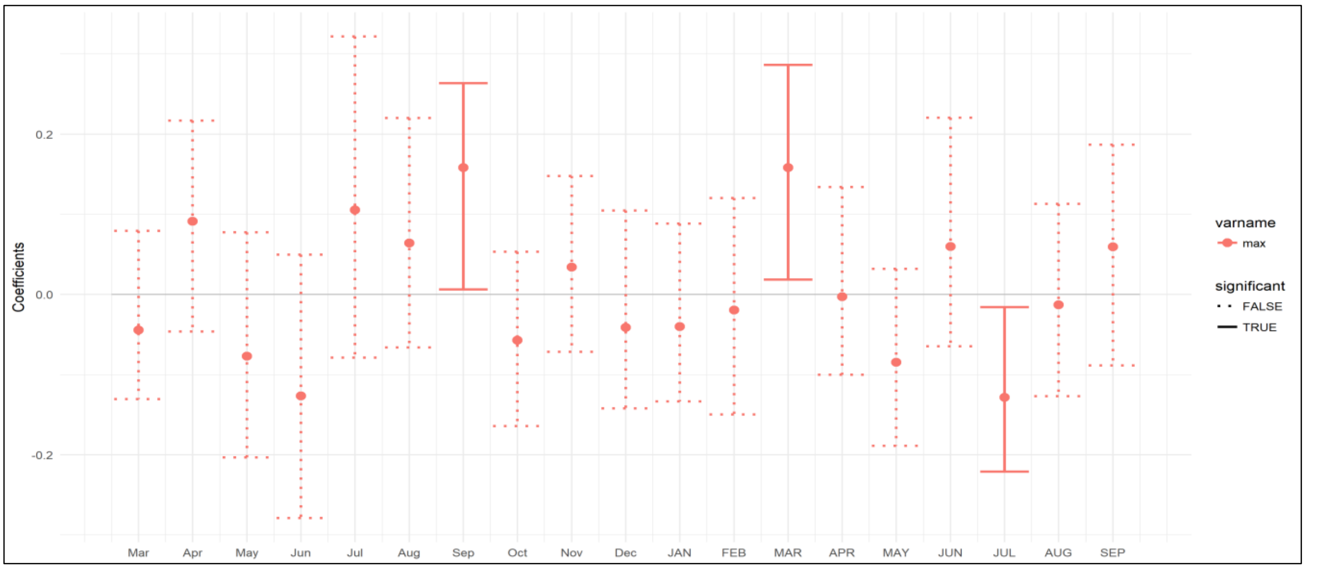

Fig. 6. Response function analysis graph of maximum temperature and tree ring growth.

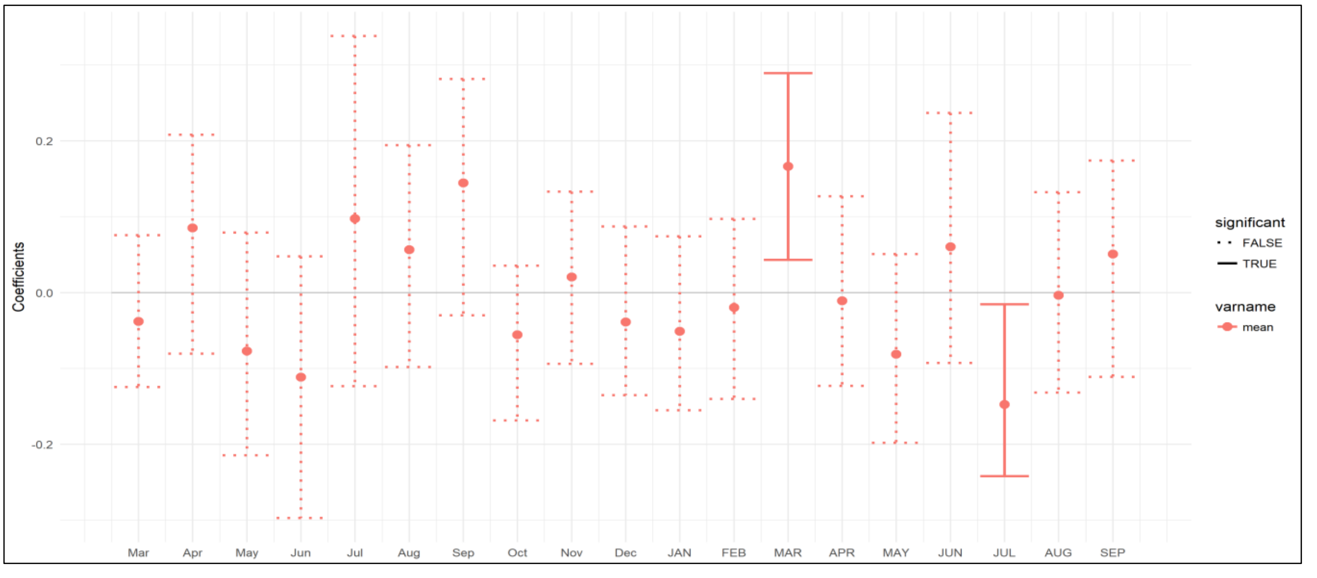

Fig. 7. Response function analysis graph of mean temperature and tree ring growth.

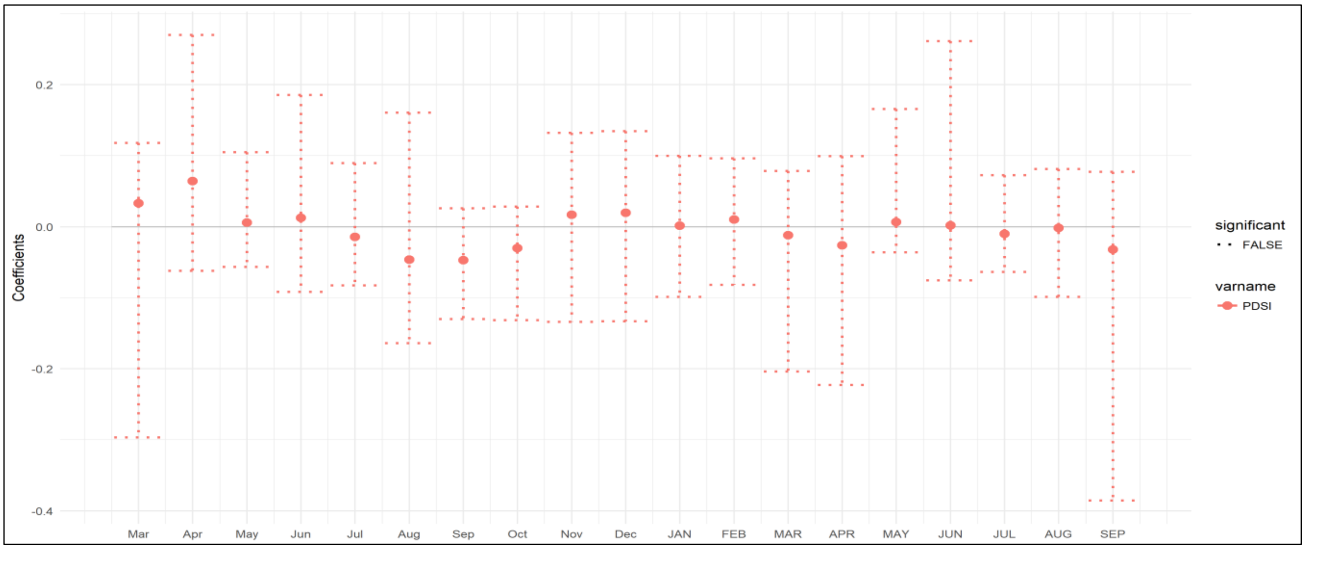

Fig. 8. Response function analysis graph of PDSI and tree ring growth.

Table 2. The table is showing the intercorrelation and sensitivity comparison of our study (SP2017) with the previous six studies. The data has been taken from ITRDB for comparison.

Chronology	Location	Chronology length	Elevation (m)	Radii vs mean	Mean sensitivity	Standard deviation	Mean	Median
mong003	48.18N 98.56E	1999-558	2420	0.654	0.1363	0.2121	0.9813	0.9742
mong008	49.22N 94.53E	1998-1641	2229	0.626	0.1205	0.1772	0.9895	0.9955
mong022	48.50N 111.4E	1996-1692	1178	0.76	0.3343	0.3506	0.9815	0.9717
mong031	48.25N 97.24E	1998-1516	2230	0.716	0.1819	0.2589	0.9839	0.985
mong002	47.46N 107.00E	1994-1506	1755	0.833	0.344	0.3793	0.9799	0.944
russ222	50.25N 84.37E	2011-1602	1898	0.582	0.1468	0.1902	0.9806	0.9667
SP2017	48.77N 86.86E	2017-1816	1900	0.502	0.1034	0.1356	0.9795	0.9772

Discussion

Our study aimed to find the previous year growing season effects on the current year tree ring width of the *Pinus sibirica* using 202-year chronology. The tree ring standardization done by ARSTAN shows means sensitivity of 0.1064 (Table 2). The tree ring width growth is showing no significant relationship to the previous year summer precipitations June and July months received the maximum amount of precipitation is resulting in the wider ring width of the current year. But in our study area, the *Pinus sibirica* tree rings not showing positive relation to the summer and winter precipitations. Our study supports the study conducted on the Douglas fir growth where a negative response found about summer precipitation indicate that the Douglas fir trees are affecting by moisture stress during the growing season, probably because of thik soil layer, more than 50% slope and scarce precipitation (Biondi, 1997).

There is significant negative relationship found of the previous year June maximum temperature on the current year tree ring width indicates that the tree ring growth of the current year negatively responded to the last year June maximum temperature. The study conducted on *Larix decidua* show that climate influence is more on growth during late winter/ early spring (Carrer *et al*., 1998). These influences have also been observed in our study that maximum temperature during the current year March significantly correlated with the tree ring width growth. As the winter continues till the end of March and start of April, but the Response Function Analysis shows that this positive relationship may be due to an increase in temperature after surviving harsh winter, giving relief in tree ring width growth.

As our chronology (SP2017) only goes up to 202 years, it indicates that we don’t have older trees. The *Pinus sibirica* life span can be as long as 800 years, so we can say that our chronology is dominated by young trees. According to (Carrer & Urbinati, 2001), young trees less than 100 years are weakly influenced by climatic variability. The table 2, showing different chronologies of the *Siberian pine* taken from International Tree Ring Data Base (ITRDB) also has a very low mean sensitivity like our chronology SP2017. *Juniperus thurifera* is also facing a decrease in mean sensitivity due to water deficiency in summers when trees cross the 100 years age showing a reduction in the height growth rate demanding for more food and water (Carrer & Urbinati, 2004). The climate-growth relationship did not change with age, indicating that trees faced the same climatic variables (Precipitation, Temperature) throughout their lives and the mean sensitivity remains constant as the tree gets old. There are nonsignificant differences between responses found in the oldest trees due to the long-term dynamic of the climate-growth relationship (Beniston, 2002), while young trees face more adverse weather conditions due to longer lasting stomatal openings found in *Pinus cembra* and *Larix decidua*. Some variation has also been observed in tree ring growth, the sex of the tree also affected the response of the tree ring growth from April temperature and summer precipitation (Rozas & Olano, 2009).

The Response Function Analysis is important for the tree ring reconstruction and climate growth-relationship. As (Briffa *et al*., 1998a; Briffa *et al*., 1998b) point out, that Response Function Analysis has fundamental implications not only for the reconstructions of climate variability but also for future climate change estimations associated with different anthropogenic activities. Late winter and early spring showing positive correlation (Fig. 9) on the tree ring growth. There negatively significant June precipitation of the previous year showing the negative effect on the current year tree ring growth. The figure indicates that *Pinus sibirica* tree ring widths are highly affected by early spring temperatures. Our results were similar to those found in (Briffa *et al*., 1998a), which found that during the period of 1895 to 1995, the tree ring growth had a significant linear trend in response to March temperatures, this is because a slight increase in March temperature increases the snow melt early, causing a reduction in the availability of moisture for tree growth.

The mean sensitivity for the *Pinus sibirica* tree species was 0.1064, showing a very low correlation between the climate and tree ring width. Several characteristics may be responsible for this, such as distance from the sampling site, elevation, or exposure. Non-availability of climatic data for the sampling site is considered to be one of the important factors for showing not the real climatic phenomena for the sampling site as weather stations at a certain distance from an area do not represent the actual climatic phenomena (Blasing & West, 1981).

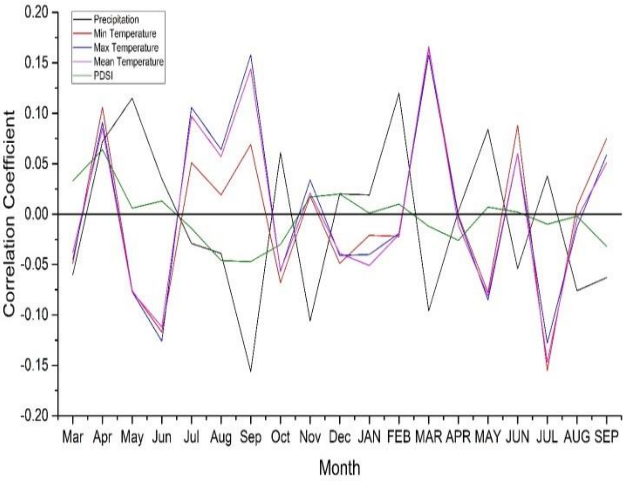

Fig. 9. Showing the monthly maximum, minimum, average temperature and PDSI relationship with tree ring growth. There is very close relationship visible in the previous June and current year March.

Conclusions

We observed in tree standardization that means sensitivity is low indicates the tree rings width of the *Pinus sibirica* poorly responding to the climate. While performing We performed the Response Function Analysis to check the monthly relationship of the previous year growing season on the current year tree-ring width, previous September maximum temperatures significant positively responding to the tree ring width as well as the late winter March mean, maximum and minimum temperature has significant positive effect on the tree ring growth. Significant negative response to the current year July temperature (mean, maximum, and minimum) and significant negative response with the previous late summer while significant positive to the previous spring precipitations. The March temperatures significant positive relationship to the tree ring growth showing positive responses to the tree ring width due to the continuing cold temperatures. However, melting snow and high exposure to strong winds, it could be possible that at the end of winter, the *Pinus sibirica* trees starts growth. However various parameters such as tree age, height, and competition among individual trees influence the climate sensitivity (Trouillier *et al*., 2018). In the future, to study the tree rings response, we should take into account some factors which highly affect the tree ring growth, e.g., the proximity of the weather station, elevation, slope, and soil.

References

Alton, P., P. North, J. Kaduk and S. Los. 2005. Radiative transfer modeling of direct and diffuse sunlight in a Siberian pine forest. *J. Geophysical Res.: Atmospheres,* 110.

Beniston, M. 2002. Climate modeling at various spatial and temporal scales: where can dendrochronology help? In *Dendrochronologia*, 117.

Biondi, F. 1997. Evolutionary and moving response functions in dendroclimatology. *Dendrochronologia,* 15.

Blanchet, G., S. Guillet, B. Calliari, C. Corona, J. Edvardsson, M. Stoffel and L. Bragazza. 2017. Impacts of regional climatic fluctuations on radial growth of Siberian and Scots pine at Mukhrino mire (central-western Siberia). *Sci. Total Environ.*, 574: 1209-1216.

Blasing, T., D. Duvick and D. West. 1981. Dendroclimatic calibration and verification using regionally averaged and single station precipitation data.

Briffa, K., F. Schweingruber, P. Jones, T. Osborn, I. Harris, S. Shiyatov, E. Vaganov and H. Grudd. 1998a. Trees tell of past climates: but are they speaking less clearly today? *Philosophical Transactions of the Royal Society of London B: Biol. Sci.*, 353: 65-73.

Briffa, K., F. Schweingruber, P. Jones, T. Osborn, S. Shiyatov and E. Vaganov. 1998b. Reduced sensitivity of recent tree-growth to temperature at high northern latitudes. *Nature,* 391: 678.

Büntgen, U., D. Frank, M. Carrer, C. Urbinati and J. Esper 2009. Improving Alpine summer temperature reconstructions by increasing sample size. *Trace,* 7: 36-43.

Carrer, M., T. Anfodillo, C. Urbinati and V. Carraro. 1998. High-altitude forest sensitivity to global warming: results from long-term and short-term analyses in the Eastern Italian Alps. In *The impacts of climate variability on forests*, 171-189. Springer.

Carrer, M. and C. Urbinati. 2001. Spatial analysis of structural and tree-ring related parameters in a timberline forest in the Italian Alps. *J. Veget. Sci.*, 12: 643-652.

Carrer, M. and C. Urbinati. 2004. Age-dependent tree-ring growth responses to climate in Larix decidua and Pinus cembra. *Ecology,* 85: 730-740.

Chen, F., H. Wang and Y. Yuan. 2017. Two centuries of temperature variation and volcanic forcing reconstructed for the northern Tibetan Plateau. *Physical Geography*.

Chen, F., Y.-J. Yuan, W.-S. Wei, T.-W. Zhang, H.-M. Shang and R. Zhang. 2014. Precipitation reconstruction for the southern Altay Mountains (China) from tree rings of Siberian spruce, reveals recent wetting trend. *Dendrochronologia,* 32: 266-272.

Cook, E., K. Briffa, S. Shiyatov, V. Mazepa and P. Jones. 1990. Data analysis. In *Methods of dendrochronology*, 97-162. Springer.

Cook, E.R. 1985. A time series analysis approach to tree ring standardization (Dendrochronology, Forestry, Dendroclimatology, Autoregressive Process).

D'Arrigo, R., G. Jacoby, N. Pederson, D. Frank, B. Buckley, B. Nachin, R. Mijiddorj and C. Dugarjav. 2000. Mongolian tree-rings, temperature sensitivity and reconstructions of Northern Hemisphere temperature. *The Holocene,* 10: 669-672.

Dos Santos, R. and A. Pereira. 1999. Palmer drought severity index for western Sao Paulo state, Brazil. *Rev. Bras. Agromet.*, 7: 139-145.

Fritts, H. 1976. 1976: Tree rings and climate. London: Academic Press.

Holmes, R.L. 1983. Computer-assisted quality control in tree-ring dating and measurement. *Tree-ring bulletin*.

Lloyd-Hughes, B. and M.A. Saunders. 2002. A drought climatology for Europe. *Int. J. Climatol.,* 22: 1571-1592.

Mishra, A.K. and V.P. Singh. 2010. A review of drought concepts. *J. Hydrol.*, 391: 202-216.

Myglan, V.S., O.C. Oidupaa and E. Vaganov. 2012. A 2367-year tree-ring chronology for the Altai–Sayan region (Mongun-Taiga Mountain Massif). *Archaeology, Ethnology and Anthropology of Eurasia,* 40: 76-83.

Nazarov, A. and V. Myglan. 2012. The possibility of construction of the 6000-year chronology on Pinus Sibirica in the Central Altai (Perspektivy postroenija 6000-letnej hronologii po sosne sibirskoj dlja territorii central'nogo Altaja). *J. Sib. Fed. Uni.,* 1.

Ntale, H.K. and T.Y. Gan. 2003. Drought indices and their application to East Africa. *Int. J. Climatol.,* 23, 1335-1357.

Oidupaa, O.C., V. Barinov, V. Serdobov and V. Myglan. 2011. Reconstruction and analysis of 1104 year tree ring chronology Tarys for Altai Sayan region (Southeastern Tuva). *J. Sib. Fed. Univ., Biol*., 368-377.

Ovchinnikov, D. and E. Vaganov. 1999. Dendrochronological characteristics of Larix sibirica L. at the upper tree line in Mountain Altai. *Sib. Ecol. J.,* 2: 145-152.

Ovtchinnikov, D., M. Adamenko and I. Panyushkina. 2000. An 1105-year tree-ring chronology in Altai Region and its application for reconstruction of summer temperatures. *Geolines*, 11: 121-122.

Politov, D.V., M.M. Belokon, O. Maluchenko, Y.S. Belokon, V. Molozhnikov, L. Mejnartowicz and K. Krutovskii. 1999. Genetic evidence of natural hybridization between Siberian stone pine, *Pinus sibirica* Du Tour, and dwarf *Siberian pine*, *P. pumila* (Pall.) Regel. *Forest Genetics,* 6: 41-48.

Rozas, V., L. DeSoto and J.M. Olano. 2009. Sex-specific, age-dependent sensitivity of tree-ring growth to climate in the dioecious tree *Juniperus thurifera. New Phytol.,* 182: 687-697.

Schweingruber, F.H., T. Bartholin, E. Schaur and K.R. Briffa. 1988. Radiodensitometric-dendroclimatological conifer chronologies from Lapland (Scandinavia) and the Alps (Switzerland). *Boreas,* 17: 559-566.

Sidorova, O.V., M. Saurer, V.S. Myglan, A. Eichler, M. Schwikowski, A.V. Kirdyanov, M.V. Bryukhanova, O.V. Gerasimova, I.A. Kalugin and A.V. Daryin. 2012. A multi-proxy approach for revealing recent climatic changes in the Russian Altai. *Climate Dynamics,* 38: 175-188.

Stokes, M.A. and T.L. Smiley. 1968. Tree-ring dating. *Tree-ring dating.*

Szeicz, J.M. and G.M. MacDonald. 1994. Age-dependent tree-ring growth responses of subarctic white spruce to climate. *Can. J. Forest Res.,* 24: 120-132.

Szeicz, J.M. and G.M. MacDonald. 1995. Dendroclimatic reconstruction of summer temperatures in northwestern Canada since AD 1638 based on age-dependent modeling. *Quarter. Res.,* 44: 257-266.

Taynik, A.V., V.V. Barinov, O.C. Oidupaa, V.S. Myglan, F. Reinig and U. Büntgen. 2016. Growth coherency and climate sensitivity of Larix sibirica at the upper treeline in the Russian Altai-Sayan Mountains. *Dendrochronologia,* 39: 10-16.

Tchebakova, N.M., R.A. Monserud and D.I. Nazimova. 1994. A Siberian vegetation model based on climatic parameters. *Can. J. Forest Res.,* 24: 1597-1607.

Trouillier, M., M. van der Maaten-Theunissen, J.E. Harvey, D. Wurth, M. Schnittler and M. Wilmking. 2018. Visualizing individual tree differences in tree-ring studies. *Forests,* 9: 216.

Yu, J., G. Zhou and Q. Liu. 2018. Tree-ring based summer temperature regime reconstruction in XiaoXing Anling Mountains, northeastern China since 1772 CE. *Palaeogeography, Palaeoclimatology, Palaeoecology,* 495: 13-23.

Received for publication 23 June 2018)