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GROWTH RESPONSE OF *PINUS WALLICHIANA* TO CLIMATIC FACTORS FROM THE CHIRAAH KARAKORAM REGION, NORTHERN PAKISTAN

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Abstract

Pinus wallichiana is the most dominant evergreen species at upper treeline, which is naturally distributed in the Karakoram region of northern Pakistan. The age of this species is reaching up to 800-years old. However, little is known the impact of the climate on the tree growth. In the present study, we developed a long (1409-2015) tree-ring width (TRW) chronology from the upper *Pinus wallichiana* forest limit to investigate its response to climate change. The TRW was significantly ($p<0.05$) correlated with the winter (December-February) temperatures and had no significant correlations with precipitation and Palmer Drought Severity Index (PDSI). These findings confirmed that the *Pinus wallichiana* tree growth was mainly limited to temperature rather than precipitation and PDSI, and suggesting that this species had a potential for the past climate reconstruction in the study area.

Key words: Climate variations, Dendroclimatology, *Pinus wallichiana*, Tree rings.

Introduction

The climatic behavior of the Hindu Kush-Karakoram-Himalaya (HKKH) Mountains is not uniform due to different weather circulation systems. The Karakoram region is nourished by winter westerly disturbance, while Himalayas region affected by monsoon (Hewitt, 2014). Paleoclimatic records for the Karakoram region is extremely limited. Most of the studies were mainly focused on short-term glacier fluctuations in the study area (Hewitt, 2005; Kaser *et al*., 2010; Iturrizaga, 2011; Gardelle *et al*., 2013; Kapnick *et al*., 2014; Rankl *et al*., 2014; Minora *et al*., 2016). Unfortunately, limited work has been done in the newly emerging field of dendrochronology, therefore, the detail knowledge about the climate-growth relationship is extremely scarce. The study area contains mature natural forest without any disturbances and having a high potential for dendroclimatic studies.

Several studies over the world have been focused on reconstruction of past climate variability by using the high resolved climate proxy of tree-ring data, such as for the Himalayas (Ahmad & Naqvi, 2005; Singh *et al*., 2009; Yadav *et al*., 2011; Krusic *et al*., 2015; Yadav *et al*., 2016; Khan *et al*., 2018), Mongolia (Davi *et al*., 2006; Davi *et al*., 2015), Tibetan Plateau and other neighboring regions (Liang *et al*., 2008; Zhu *et al*., 2009; Fang *et al*., 2010; Zhu *et al*., 2011; Chen *et al*., 2012; Azizi *et al*., 2013; Yang *et al*., 2014; Chen *et al*., 2015; Wang and Liu, 2016). The Karakoram region has a large area of natural forest, whereas a few studies were documented to analyze the impact of the climate on the tree growth (Esper, 2000; Esper *et al*., 2002; Esper *et al*., 2007; Zafar *et al*., 2015), despite of the high dendroclimatological potential (Ahmed *et al*., 2011).

The goal of this study is to develop a tree-ring chronology of *Pinus wallichiana* (hereafter *P. wallichiana*) and to examine the climate-growth response between climate and standard ring width chronology. *P. wallichiana* has been used less frequently for dendroclimatological investigation from high elevation site in the Karakoram region, northern Pakistan.

Material and Methods

Tree-ring sampling site: The Chiraah (36°.03N, 74°.56E) valley is located in a per-humid area in the high-altitude northwestern region of Pakistan (Fig. 1). From the valley bottom to the uppermost Nanga-Parbat massif elevation ranging from 1202 to 8126 m a.s.l (Shroder *et al*., 2000). The climate of the study area shows great variations, in the high elevation (glacier region), receives higher precipitation than the valley bottoms (Kick, 1980). The South-Asian summer monsoon is dominant during summer, while during the winter season mid-latitude westerly circulation nourishes these mountains (Owen *et al*., 2002; Kapnick *et al*., 2014).

According to the meteorological record of Gilgit at the valley floor (74° 20' E, 35° 55' N, 1460 m a.s.l, from 1955-2013), the annual mean temperature is 15.98°C. The monthly mean temperature ranges from 3.69°C (January) to 27.34°C (July; Fig. 2). The total annual precipitation is 138.34 mm, of which 15.91 % falls in the winter and spring season (January-May), while 5.16 % precipitation is recorded in the summer season (June to September). Precipitation in this region increase from low to high elevation. For example, the mean annual precipitation at Astore station is 488 mm (74° 54' E, 35° 22' N, 2167 m a.s.l, from 1955-2013), while at Burzil station (4,030 m a.s.l, from 1995-2011) it is 870 mm year^{-1}.

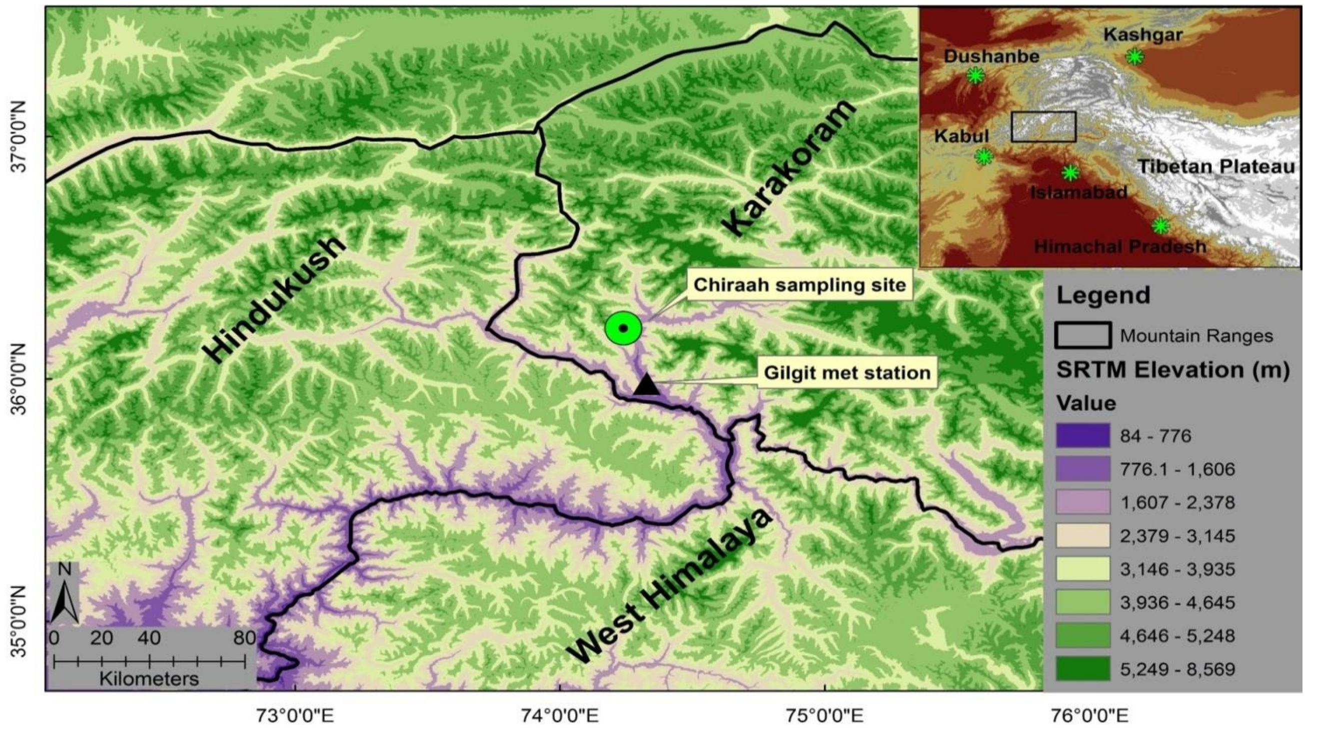

Fig. 1. Tree-ring sampling site and location of the Gilgit meteorological station in the Karakoram, northern Pakistan.

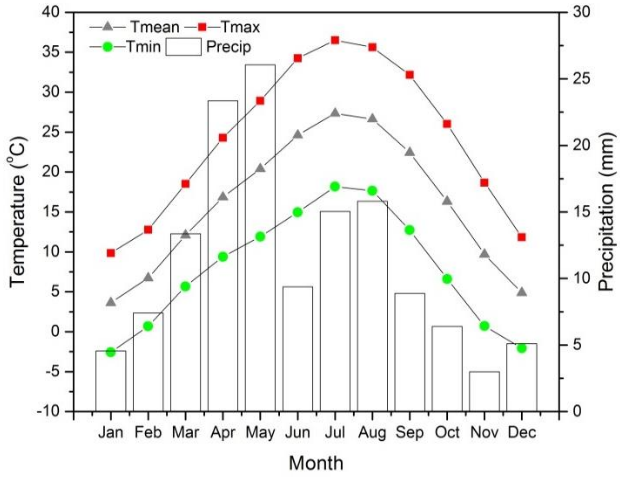

Fig. 2. Climate diagram of the Gilgit instrumental records, based on the maximum, minimum and mean temperatures and total precipitation from 1955 to 2013.

Table 1. Sampling site characteristics and summary statistics for the TRW chronology.

Chronology site	Chiraah valley
Species	***Pinus wallichiana***
Latitude (N)	36°03
Longitude (E)	74°56
Elevation range (m)	3010-3350
Cores/trees	71/52
Time span	1409–2015
Series inter-correlation	0.53
Mean sensitivity	0.21
Mean-correlation among all series	0.40
Mean-correlation within a tree	0.41
Signal to noise ratio (SNR)	18.15
Expressed-population-signal (EPS)	0.91

Tree-ring data and TRW chronology development: *P. wallichiana* is a dominant tree of naturally open forest in the Karakoram region of northern Pakistan. It is generally growing at altitudes ranging from 1800 to 5000 m a.s.l (Ahmed *et al.*, 2011), having steep rocky slopes with thin soils. We extracted the increment cores from healthy trees from Chiraah valley, between 3010 and 3350 m a.s.l with no human interference and fire disturbance. 71 tree cores were extracted from 52 living *P. wallichiana* at breast height (1.37 meters above the ground level; Table 1) in July 2015. The cores were stored in labeled straws in the field to minimize mechanical damage during transport. The tree cores were air dried, glued (fixed) on the wooden slots, and fine-sanded for visual cross-dating following standard dendrochronological techniques (Stokes and Smiley, 1968). We measured tree-ring widths using a LINTAB 6 measuring system with a 0.01 mm resolution (Frank Rinn S.A., Heidelberg, Germany). The tree-ring samples were cross-dated by matching the tree-ring width visually utilizing TSAPWin software, and then the Computer program COFECHA (Holmes, 1983) was used to validate the results of the crossdating.

Detrending and standardization of the raw measurement series were achieved utilizing the Computer program ARSTAN (Cook, 1985). We detrended the raw ring-width series using Negative Exponential Curves to remove the low-frequency growth trend due to tree ages (Cook & Kairiukstis, 1990). Then the detrended tree ring width index series was biweightly averaged into a chronology (STD) to enhance the common variability among different trees (Cook, 1985). The common interval analysis during the period of 1900–2015 was used to investigate the chronology signal strength, such as the Expressed Population Signal (EPS), correlations between trees (Rbar), and Mean Sensitivity (MS) (Fritts, 1976). EPS is usually used to assess the representation of the samples to the full population. Rbar is calculated as mean correlations between all the trees to show the common signal strength between different trees, while MS describes year to year discrepancy of tree growth (Fritts, 1976). We also did moving interval analysis of the EPS and Rbar with 50-year intervals lagged by 25 years to determine at what point the number of cores was enough to present a reliable part of the tree-ring chronologies (Cook & Kairiukstis, 1990).

Climate signal analysis: To investigate the climatic response to the tree growth, we performed the correlation analysis between the TRW chronology and climate data over the period of 1955-2013. The temperature and precipitation data were taken from the nearby Gilgit weather station, which comprises monthly maximum, minimum and mean temperatures and monthly sum precipitation. We also calculated the drought growth relationship with Palmer Drought Severity Index (PDSI; from 1955-2013). The PDSI data were retrieved from the self-calibrating CRU scPDSI 3.24 dataset (36° 25′N, 74° 75′E) for 1955 to 2015. The climate data from September of the prior year to November of current growth year were used for the analysis, as considering the previous year climate may also have an influence on tree growth (Fritts, 1976).

Results and Discussion

TRW chronologies and their statistics: After Crossdating, the final TRW chronology of *P. wallichiana* trees were developed for the Karakoram region of northern Pakistan. This chronology spanned six hundred and nine years (AD 1409-2015), included of seventy-one cores from fifty-two trees (Fig. 3). The reliable chronology was shortened, when the EPS values were greater than the standard threshold ($p>0.85$) after AD 1760, to have at least 20 cores. This designates the mark to which the precise sample-chronology represents a hypothetically reliable-chronology (Wigley *et al*., 1984). The chronology shows a long visible trend which is fluctuated along with the mean (0.97; consider the reliable part of the chronology) during the AD 1760 to 1950, followed by lower trend from AD 1951-1985. The long-term increasing trend was observed during the last three decades. The statistics of the chronology over the period common to all trees (for the period of 1900–2013, Table 1) revealed the reliable cross-dating and common climatic signal. Therefore, for further analysis, we used the tree-ring chronology from 1760 with an EPS greater than 0.85.

Climate-growth assessment: Results of the correlation analysis showed that temperature is the major controlling climatic factor for tree-growth at higher elevation in the study area. The influence of temperature is strong and significant from the prior year December to current year February ($p<0.05$, Fig. 4a). Among the different combinations of seasonal variables, December-February mean temperature had the highest correlation of 0.50 ($p<0.01$) with the STD chronology. In contrast to the significant and positive correlation between temperature variables and STD, neither the precipitation nor the PDSI showed a significant relationship with STD. The climate-growth assessment showed that the seasonal climatic variables particularly, temperature have more influence on tree growth than individual months. The results reveal that temperature rather than precipitation is the essential limiting climate feature for tree-growth at higher elevation in the Karakoram region.

The positive association of tree growth to December-February temperature during 1955–2013, could be inferred in terms of known physiological processes (Shi *et al*., 2016). Due to low/freezing temperature, ice-crystals may be formed in plant tissues desiccating cells and disrupting membranes (Körner, 1998). Similarly, frozen soil also inhibits water absorption and results in winter dryness, injuries to buds/needles and reduces trees potential for future tree growth (Pallardy, 2010). Moreover, freezing/low temperature and stressful environment (deep snow-cover) maybe lead to slower and later initiation of spring growth (Fritts, 1976), and shortening the tree growing season. In contrast, above mean warm winter conditions reduce root injuries/ plant mortality and/or less physiological injuries encourage the photosynthetic rate, synthesization, and storage of carbohydrates that could be used in the subsequent growing seasons (Chapin *et al*., 2005; Gou *et al*., 2007). A similar positive effect of December-February temperature on radial growth for Karakoram region have been reported by Esper *et al.,* (2002), Ahmed *et al*., 2010, 2011, 2012, 2013, and Asad *et al*., (2016). Comparable response patterns also documented for several tree species in the nearby region (Pederson *et al*., 2004; Liang *et al*., 2006; Shi *et al*., 2012). However, our findings showed disparity to a previous study by Zafar *et al*., (2015). They reported that the tree growth was negatively correlated with summer (JJA) temperature, which was remarkable for the treeline sites (for detail see "Asad *et al*., 2016"). Because choosing trees from sites at higher elevation is crucial for the retrieving of temperature rather than precipitation (Fritts, 1976; Körner, 2007). Therefore, the growth of trees at upper timberline in the study area was significantly correlated with temperature (encourages the growth of the trees) and insignificantly associated with precipitation.

Conclusions

We documented a new TRW chronology from the Karakoram region of northern Pakistan. The association between the TRW and climate variables revealed the winter (December-February) mean temperature have a significant influence on the tree growth. TRW chronologies are weakly correlated with precipitation and PDSI. According to these findings, the temperature is the crucial climatic factor for the growth of *P. wallichiana* at higher elevation in Chiraah Karakoram region, northern Pakistan. Since our study is based on only one tree-ring site and flexible standardization method, further tree-ring network studies and regional growth-curve standardization methods (Melvin & Briffa, 2008) are recommended to extend both the timescale and the spatial content of our knowledge on Karakoram climate variability. *P. wallichiana* trees could reach ages of more than 800 years and sensitive to climate in several areas of the Karakoram region. Hence, there is also high potential to use *P. wallichiana* tree rings from the Karakoram to reconstruct the climate variability in millennial scale.

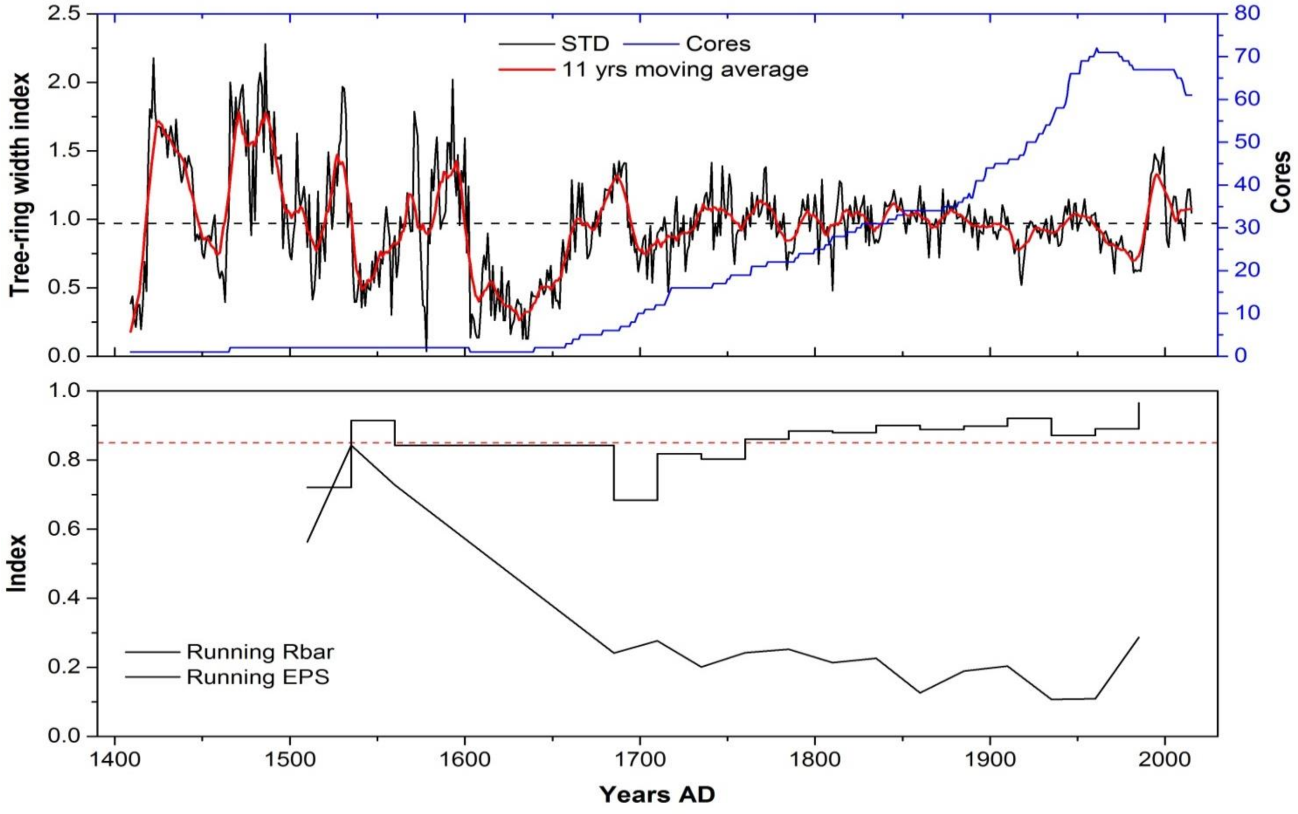

Fig. 3. Tree-ring width (TRW) chronology from 1409 to 2015, its long-mean (horizontal dashed line), 11 years moving average (thick red line) and number tree cores (thick blue curve) (above penal), running inter-series correlation (Rbar), and Expressed population signal (EPS) over time, the horizontal dashed line marks EPS > 0.85 (below penal).

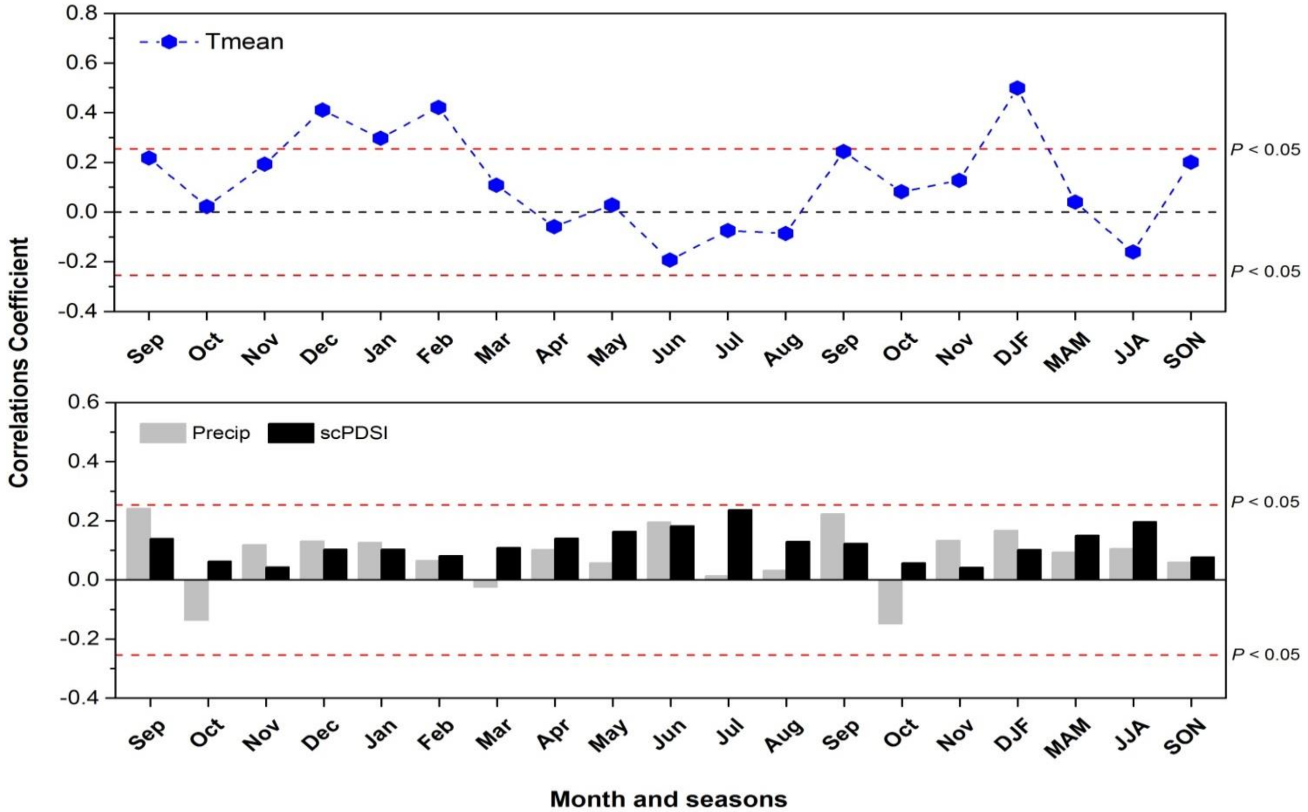

Fig. 4. The correlations between the tree-ring width (TRW) with climate factors from prior year September to the current year November, using data from Gilgit meteorological station from 1955 to 2013. DJF, MAM, JJA, and SON represent winter, pre-monsoon, monsoon and autumn seasons, respectively.

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