Research Article

Growth Response of Himalayan Spruce to Climate Change in Dry and Moist Temperate Forests of Pakistan

Tanvir Hussain[1,2]*, Kafeel Ahmad[2], Asif Ali[1], Nazir Ullah[1], Muhammad Inamullah Khan[3], Kamal Khan Kakar[1] and Said Akhtar Khan[1]

[1]Pakistan Forest Institute, Peshawar; [2]Centre of Biotechnology & Microbiology, University of Peshawar; [3]Department of Environmental Sciences, The University of Haripur.

Abstract | Growth response of trees in the context of climate change has important implications for future forest dynamics, accurate carbon accounting and sustainable forest management.The present study was conducted to assess the growth response of Himalayan Spruce growing in the dry and moist temperate forests of Khyber Pakhtunkhwa to climate change. Dendrochronological techniques were used for collection of tree ring cores, development of tree ring width chronologies and growth-climate relationship. The population of moist temperate forest of Barkan Usheri (BAR), reflected more climatic information i.e., average mean sensitivity (0.23), signal-to noise-ratio (23.05) and overall sample representativeness (EPS= 0.985 & Rbar=0.92) were all higher than population growing in dry temperate forest of Bomborate (BOM). Climate-growth relationship revealed that precipitation had a significant and positive influence on the growth of both populations and acting as limiting factor while this correlation with temperature and Palmer Drought Severity Index (PDSI) at both sites was recorded non-significant. In BOM an incraesing trend in growth was recorded, whereas in BAR no prominent growth trend was seen. It was concluded that, Himalayan Spruce has great potential for studying growth-climate relationship and the results of this study could be helpful to forecast regional and global climate change by reconstructing past climatic factors.

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***Correspondence** | Tanvir Hussain, Pakistan Forest Institute, Peshawar; **Email:** sthkhan75@gmail.com
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Introduction

Climatic factors like temperature and precipitation plays vital role in the growth and development of trees. They can produce long-term responses to climate changes and extreme events and are recorded as information in the annual ring width (Duchesne *et al*, 2017). Tree rings have become a key source of studying the impact of climate changes on tree growth and reconstructing past climatic factors (Smerdon *et al*, 2013) in view of easy sampling, accurate dating, high resolution, strong continuity and wide distribution (Wu, 1990). In the recent past years, growth-climatic relationships have been explored by many researchers in the region e.g., Rauf *et al*. (2022) studied climate-growth response of Himalayan Fir (*Abies pindrow*) growing in moist temperate forests of Ayubia, Bara Galli and Kuldana of Khyber Pakhtunkhwa province Ullah *et al.* (2022) in Spruce (*Picea smithiana*) and Himalayan Fir (*Abies pindrow*) growing in Northern areas of Pakistan; Amir *et al.* (2022) in Himalayan Fir (*Abies pindrow*), Deodar (*Cedrrus deodara*), Blue pine (*Pinus wallichiana*) and Yew (*Taxus Baccata*) growing in Ayubia National Park; Shah *et al.* (2019) in Spruce *(Picea smithiana)* growing in Kalam and Kaghan Valleys; Bukhari *et al.* (2019) in Blue pine (*Pinus wallichiana*) growing in Galliat; Asad *et al.* (2017) in Blue pine (*Pinus wallichiana*) growing in Korakoram, Pakistan. Many more Himalayan conifers and broad-leaved tree species have been successfully investigated for dendroclimatic purposes but these are limited to eastern Himalaya (Ahmed *et al.*, 2011).

Pakistan ranks 8th most vulnerable country to climate change (Eckstein *et al.*, 2020). Climate data for the previous century (1901-2000) have shown an increase of 0.6 °C in temperature and +25% in precipitation (Sheikh *et al.*, 2015). This rise in temperature closely accompanied with the global rise in temperature (0.6°C) over the previous century (1901-2000). Khyber Pakhtunkhwa is one of the most vulnerable provinces of Pakistan in view of the negative impact of climate change. It is speculated that the moist temperate forests of Himalaya with an elevation of 1525-3660 m (lower Kaghan valley, Galliate and southern part of Kohistan) will experience intense precipitation due to climate change (Pachauri *et al.*, 2014).

Picea smithiana is an important species of coniferous biome in the mountainous areas of Pakistan. It is fairly common at a high elevation from 2500-3300 m in the dry temperate and moist temperate forests of Dir, Chitral, Azad Kashmir, Murree Hills, Hazara, Swat and Kurram agency (Sheik, 1993; Ahmed and Naqvi, 2005). It provides important economic and ecological services as its wood is used in constructional work, railway sleeper, packing cases and in pulp and mulch (Siddiqui and Mahmood, 1996). This species has been declared as endangered or vulnerable in view of climate change and anthropogenic activities in the region (Khan, 2004). Further, little or no work on the growth response of *Picea smithiana* growing in Barkan Usheri and Bomborate to climate change is reported.

Keeping in view the above scenario, the present study was designed with the objective to i) Develop study sites tree ring width (TRW)) chronology ii) Explore the growth responses of this tree species to the changing climatic conditions in dry and moist temperate forests of Khyber Pakhtunkhwa, Pakkistan over 1965-2015 and iii) Provide a basis for its future protection in the region for better forests management.

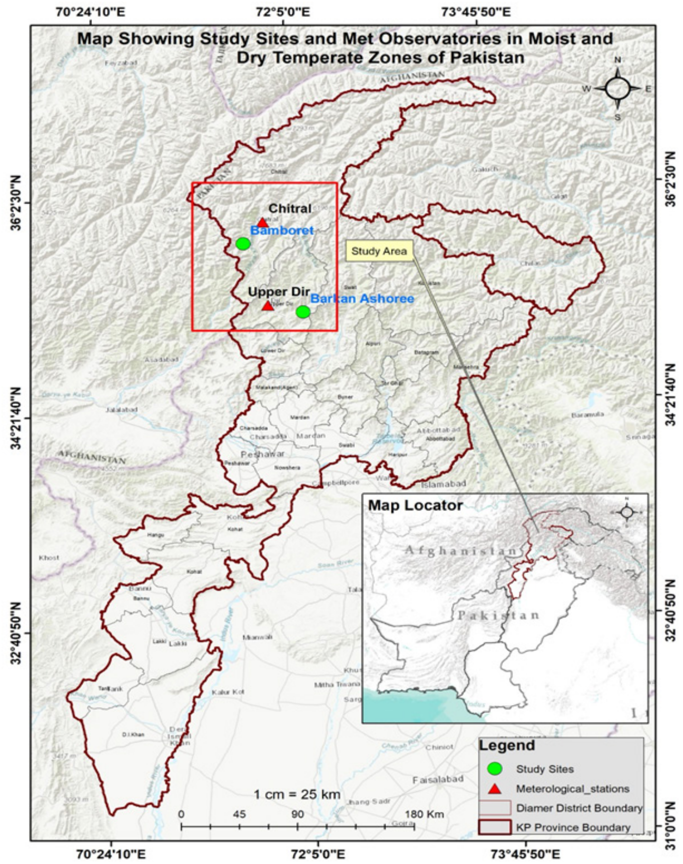

Figure 1: *Map showing study sites and meteorological observatories in khyber pakhtunkhwa, pakistan.*

Materials and Methods

Study sites

Figure 1 shows the locations of study sites and table1 represent the geographic and topographic characteristics of the sampling areas. Barkan Usheri a moist temperate forest lies in Dir Forest Division of Khyber Pakhtunkhwa province of Pakistan. The region is dominated by mountains and hills of east Hindukush ranges and has uneven and rough topography (Krishnan *et al.*, 2019). At different locations, temperature variation is prominent within the month and during different months of the year. On upper areas, snow falling generally start at the end of November and moves downward in December and depending of height, it begins to melt in March and continues into April (Banskota, 2000). Bommburate, situated in Chitral Forest Division and exhibited dry temperate climatic conditions. The main natural species found in the valley are Deodar, Kail, Fir, Spruce, and other broadleaved species. It observed hot summers in the south (Arandu-3500 m a.s.1.) to continuously arid and cold in the north (Broghil-12480 m a.s.1.). Generally, the summers are cool and pleasant; the winters are pretty cold. Frost is common and starts in November. The severe frost occurs in December and January. Snow starts falling on high peaks during October. By December, except for a narrow belt along Chitral River, the entire district is covered with 4 to 16 feet deep snow. The snow melts away by the end of May. The elevations above 20,000 feet remain under perpetual snow. The rainfall is scanty and erratic. The bulk of the annual precipitation (about 75%) is received in winter (December-May)(Ghani, 2020).

Climatic data

Due to limited availability of Metereological station data at study sites, climate data i.e., mean temperature, annual precipitation and PDSI from international source Climate Research Unit (CRU) (Osborn and Jones, 2014) was utilized for climate-growth relationship. The grid size of 0.5x0.50 (50 km x 50 km) was used for scaling down study area (Bukhari *et al*., 2019). The climatic parameters i.e., annual mean temperature and annual total precipitation were used to explore the climate regime and climate change over 1965-2015.

From the climatic data of Barkan Usheri, Upper Dir Forest areas (Figure 2a & Table 2) it was calculated that July was the hottest month with a mean temperature of 20.41 $^{\circ}$C and monthly mean rainfall of 76.79 mm. The coldest month was recorded January (-0.84 ^{0}C) with precipitation of 62.90 mm. The maximum rainfall of 117.15 mm was measured during March along with the monthly mean temperature of 4.46 ^{0}C. A significant increase of 0.76 ^{0}C ($r=0.43$; $p<0.002$) in annual temperature and a non-significant ($r=0.09$; $p>0.05$) increase of 45.2 mm in total annual precipitation was calculated for this studied period. As for as PDSI is concerned, no significant change was recorded for this study area.

It is evident from the climate diagram of Bomborate, Chitral Forest Division (Figure 2b & Table 2) that July was the hottest month with a maximum mean temperature of 17.77 ^{0}C along with mean rainfall of 50.72 mm while January was recorded as the coldest month with a minimum mean temperature of -4.58 ^{0}C and mean monthly rainfall of 58.55 mm.

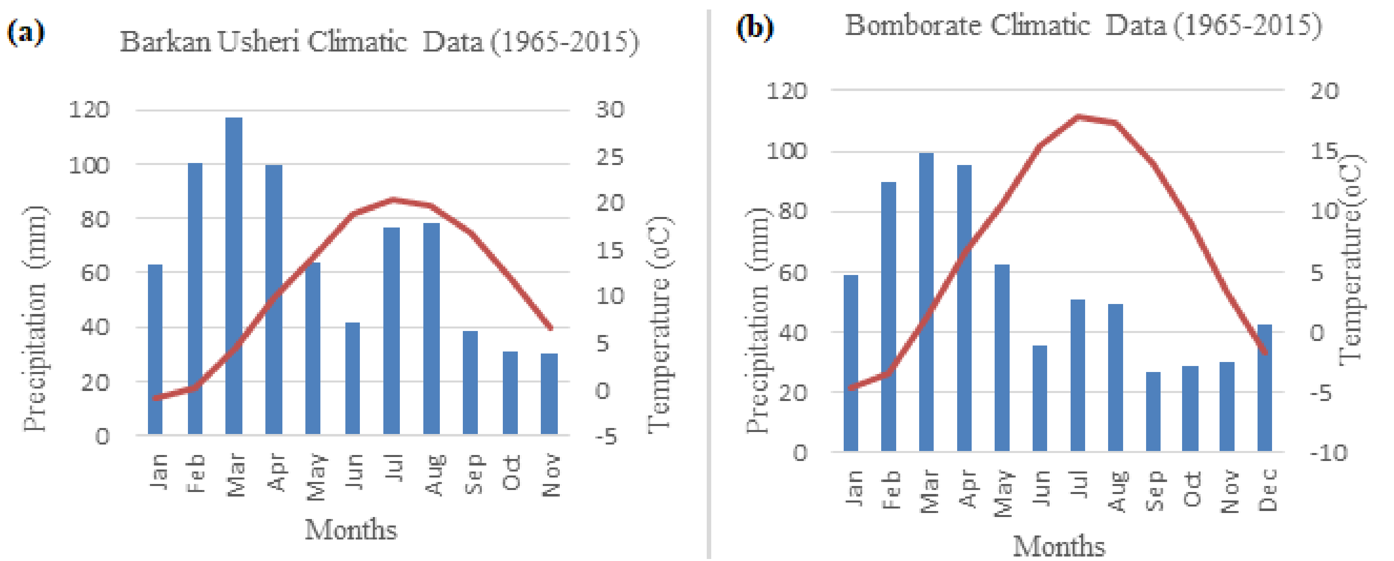

Figure 2: *Monthly variation in mean annual precipitation (bars) and mean annual temperatute (line) in (a) Barkan (b) Bomborate, calculated for the period of 1965-2015.*

Table 1: *Geographic and topographic features of study sites of khyber pakhtunkhwa, pakistan.*

Forest Type	Met. Observatory Stations	Study Sites	Coordinate		Elevation (m)	Slope (%)	Aspect
			Longitude (E)	Latitude (N)	Min-Max	Min-Max	
MTF	Dir	Barkan Usheri	71.908905556	35.265986111	1610-2684	17-33	N
DTF	Chitral	Bamborate	71.652538889	35.687111111	2295-2887	36-70	N

MTF =Moist Temperate Forests, DTF=Dry Temperate Forests

Table 2: *Temperature and precipitation regimes over study sites of Khyber Pakhtunkhwa.*

Study Sites	Period	Temp. (^{0}C) (Min – Max)	Prcp. (mm) (Min – Max)	PDSI	Ince/Dec Temp. (^{0}C)	Inc/Dec Precipitation (mm)	Ince/Dec PDSI
BAR	1965-2015	9.16-12.21	523.2-1210.6	-2.97-2.42	0.76*	45.20 NS	0.28 NS
BOR	1965-2015	5.71-7.98	395.6-937.7	-2.74-3.73	0.88*	29.2 NS	0.029NS

*Min=minimum, Max=maximum, NS=non-significant, *=significant(p<0.05), Incr= Increase, Dec=Decrease*

The maximum total annual rainfall of 937.70 mm was measured during 1965 with an annual mean temperature of 6.43 ^{0}C. An increase of 0.88 ^{0}C ($r=0.48$; $p<0.001$) and a non-significant increase of 29.2 mm in total annual precipitation were calculated for this studied period. In case of PDSI, no proninent change was calculated for this region.

Sample collection and processing

For sampling, those trees were selected which were old, healthy, free from severe competition with neighbors, and anthropogenic disturbances. 20-30 trees were selected in each study site (Table 1) by following the Simple Random Sampling Method and at DBH (Diameter at breast height) of each tree, cores (wood sample) were extracted with the help of an increment borer. The collected cores were air-dried for two to three days. After fastening with glue on wooden core holders and properly label, the dried cores were then subjected to the sanding process by using sanding paper of different grit (Orvis and Grissino-Mayer, 2002) for producing a smooth surface. The best-surfaced cores free from defects were selected and pointer years were marked under a stereomicroscope using the skeleton plot method as described by Stock and Smily (1968). Each core cross-dated (pattern matching) with other cores of the same site. The tree ring feature i.e., tree ring widths (mm) was measured with WinDendro System (WINDENDRO, 2014a). For this process, all the cores were scanned with calibrated WinDendro Scanner at more than 600 dpi (dot per inch) resolution. The images were saved in Tiff format (Tagged information file format) and the measurement of tree ring features was carried out as described in the manual of WinDendro System software 2014(WINDENDRO, 2014a). In order to check the quality of cross-dating of tree ring series the raw data was subjected to a computer-based program Cofecha (Holmes, 1994; Grissino-Mayer, 2001).

Chronology development

It is not recommended by the tree ring researchers to use raw tree ring series for studying past climatic variations because it reflect small signals. In order to enhance these signals, standardization procedure i.e., cubic spline was adopted using software ARSTAN (Auto-regressive Standardization) which removed age, non-climatic trends and unwanted information like noise from the tree ring series and maximized the required variations as explained by Cook and Briffa (1990). Four chronologies i.e., raw, standard, residual and arstan were obtained by this analysis and residual chronology for this study was utilized.This program also gave various statistics like EPS, SNR and EPS which were used to determine the quality of a chronology (Ahmed and Wahab, 2010). To strengthen the reliability of developed chronologies, pointer and event years of each study site chronology were determined using pointRes program of R packages (Van der *et al*., 2015).

Climate-growth relationship

To find which chronology best suited for the establishment of the growth-climate relationship, the preliminary correlation was developed between CRU climatic factors and site chronologies. The residual chronology was found more suitable and therefore, it was used for the establishment of growth-climate relationship by Correlation Function Analysis (RFA) using "treeclim" software of R package (Zang and Biondi, 2015; Misi *et al*., 2019). The Pearson correlation coefficient was determined among tree ring chronology and climatic factors i.e., monthly mean temperature, monthly annual precipitation and PDSI from previous year October to October of the current growth year (Ahmed *et al*., 2011) as considering the previous year climate may also have an influence on tree growth. The trend analysis of growth for the period 1965-2015 was assessed through Mann-Kendall Test (Bukhari *et al*., 2019; Misi *et al*., 2019).

Results

Tree Ring width Chronologies and their Statistics

After cross dating, the final chronologies of Himalayan Spruce for each study site were developed. Table 3 showed the summarized results of COFECHA and

Table 3: *COFECHA and ARSTAN Statistics of tree ring chronologies from both study sites.*

Sites	COFECHA							ARSTAN		
	Chronology Span	Years	[1]Corr with Master	[2]Mean msmt	[3]Std Dev	[4]Auto Corr	[5]Mean Sens	[6]Rbar	[7]SNR	[8]EPS
BAR	1894-2015	122	0.506	1.48	0.708	0.738	0.235	0.920	23.052	0.958
BOM	1872-2015	144	0.776	1.59	0.742	0.865	0.155	0.349	8.031	0.889

1= Correlation with Master Chronology, 2= Mean measurements, 3= Standard Deviation, 4= Auto-correlation, 5= Mean sensitivity, 6= mean inter- series correlation, 7= Signal-to-noise ratio, 8= Expressed population signal.

ARSTAN programmes for both chronologies. The chronology developed for Barkan Usheri spanned 122 years (AD 1894-2015) and 144 years (AD 1872-2015) for Bomborate. The correlation with master chronology tells the correlation between two cores, time series, or correlation of one core with master chronology. It shows the common stand-level signal for any site and provides first valuable information about the suitability of any chronology. Its value varies from site to site and species to species and Table 3 showed that both the chronologies possessed acceptable value for this species. The mean ring witdh measurement value indicated the wider or narrow ring patterns of the tree and it also help to find the growth pattern of the species. Himalayan Spruce growing in Bomborate showed a litle bit faster growth than in Barkan Usheri. Mean sensitivity is one of the most important characters which shows the suitability of the core samples (Fritts and Shatz, 1975). It calculate the proportional variation in TRW from one year to the next (Fritts, 1974). It varies from site to site and species to species and ranging from 0 to 1. Cofecha analysis reflected that Usheri Barkan is more sensitive site for Himalayan Spruce than Bomborat. Mean inter-series correlation (Rbar) tells the signal strength of the chronology and explores the common signal strength of the series based upon the sample depth (Cook *et al*., 2000) and ARSTAN analysis showed stronger signal stength in Spruce growing in the Usheri Barkan population than Bomborate. A value of 0.85 is consider reasonable for expressed population signal (EPS), which also determines the confidence and strength of common signal in the chronology. However, no minimum value is established to ensure that a chronology is suitable for studying climate growth relationship to reconstruct past climatic factors (Briffa *et al*., 1988; Ahmed *et al*., 2010). According to ARSTAN results given in Table 3 both chronologies scored the sophisticated value of EPS for studying climate-growth relationship. Signal-to-noise ratio (SNR) is an expression of the strength of the observed common signal among tree ring indices in the essemble (Wigley *et al*., 1984) and its high value indicated higher climatic signals in the chronology (Zafar *et al*., 2010; Fritts, 1976). Table 3 showed that the higher suitable SNR value was found in the chronology of Barkan Usheri (23.052).

Event years are the years with a remarkable increase or decrease in growth whereas the term pointer years refers to years with remarkable growth responses at the stand level (Schweingruber *et al*., 1990). Following are the pointer years and event years found in the chronologies of both study sites (Figures 4a & b).

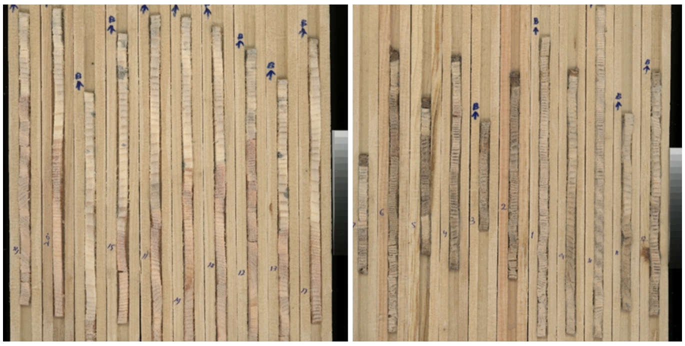

Figure 3: *Some scanned cores images picea smithiana with windendro scanner 4800. (a) Barkan usheri (b) Bomborate.*

Growth trend

In Barkan Usheri no prominent trend in the growth of *Picea smithiana* was recorded, however, under the dry temperate climatic conditions of both Bomborate, the upward trend in growth features was recorded (Table 4).

Table 4: *Pointer years and event years found in the chronologies.*

Barkan usheri	Bomborate
Positive pointer year(s): 1910	1879,1893,1894,1906,1913,1950,1975,1986,1996
Negative pointer years: Nil.	1935
Positive event years: 1909	1887,1918,1925,1939,1943,1961,1981
Negative event years: 1903,1904,1911	1966

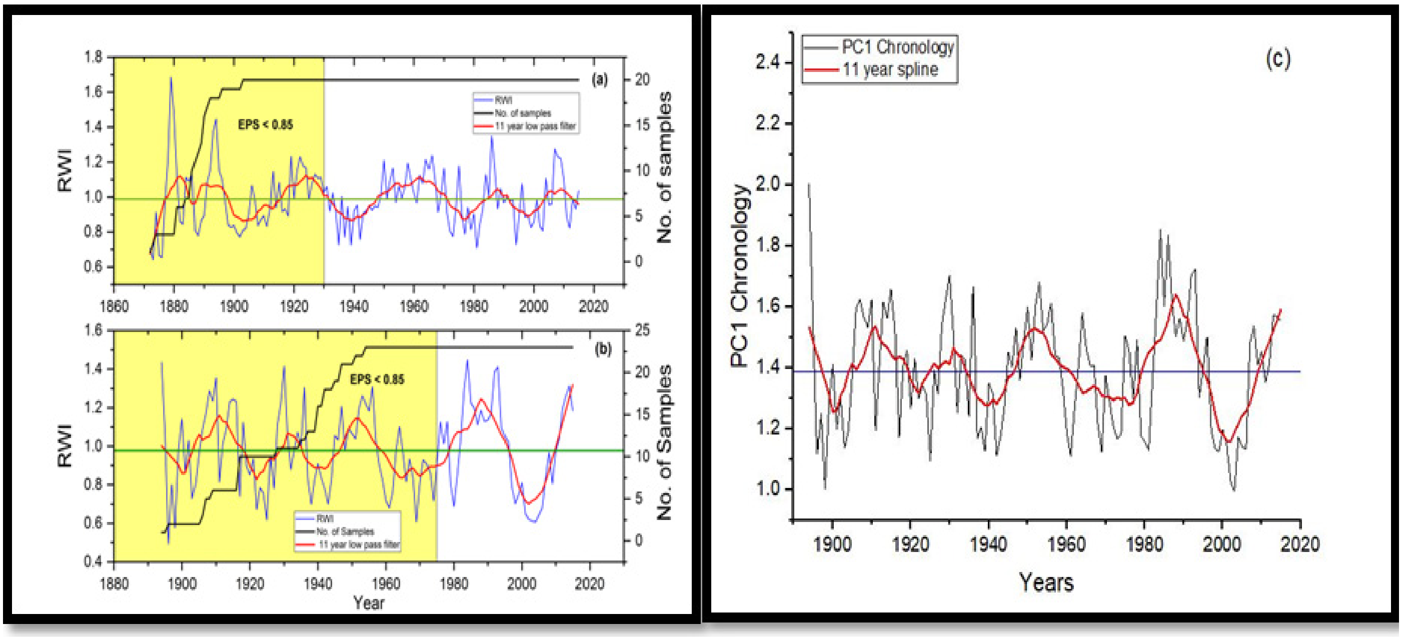

Figure 4: *The regional tree ring width chronology of Picea smithiana growing in (a) Barkan (AD1894-2015) (b) Bomborate (AD1872-2015) with EPS<0.85 cut and 11 years low pass (red line) and sample depth (black line). (c) PC1 Chronology for both sites.*

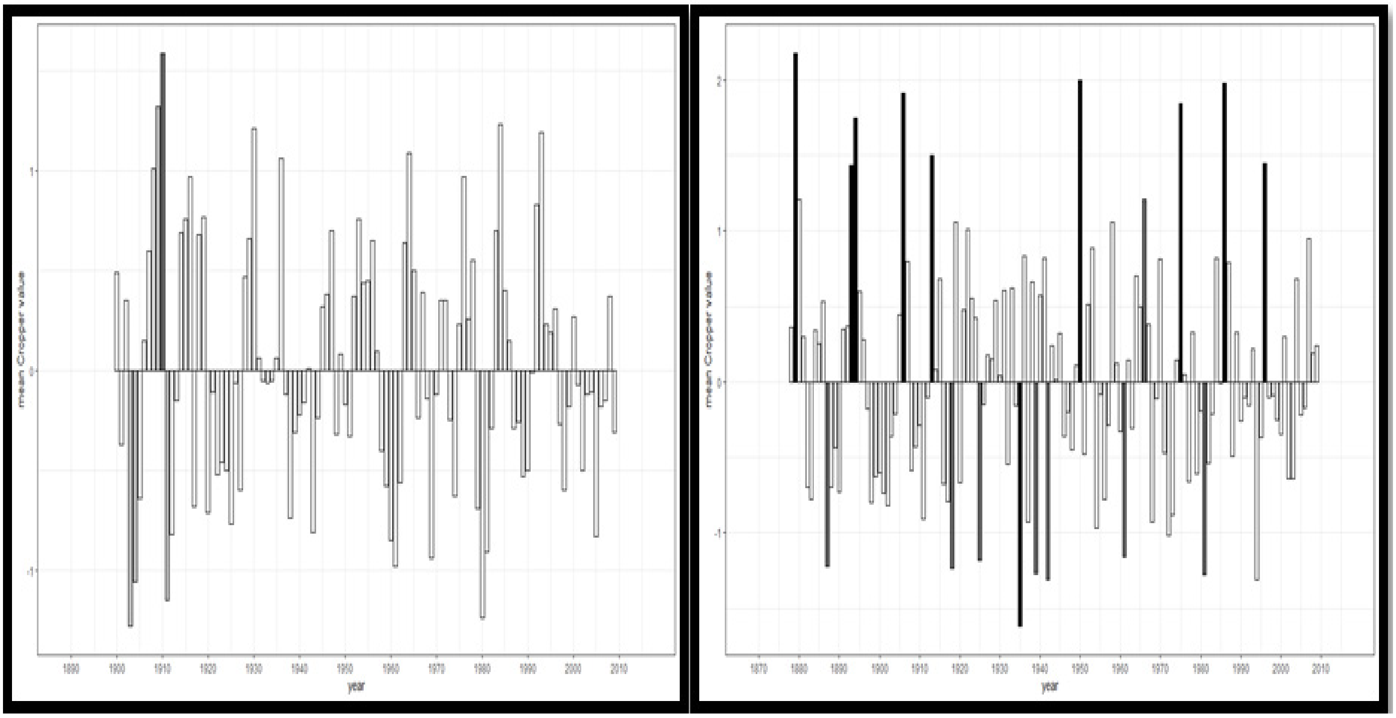

Figure 5: *Positive and negative pointer (dark gray bar) and event years (gray bar) of Picea smithiana growing in (a) Barkan (1894-2015 AD) (b) Bomborate (1872-2015 AD).*

Growth-climate relationship

Figure 5 represents the growth-climate interaction of *Picea smithiana* growing under the prevailing moist temperate conditions of BAR and dry temperate of BOM. The results of Correlation Function analysis at BAR showed a positive and significant correlation ($r=0.35; p<0.05$) between rainfall and the growth characteristic in the month of July of the current growth year (Figure 5a). This revealed that precipitation is acting as limitiing factor for the growth of this species growing in BAR. A significant but negative correlation ($r=-0.50; p<0.05$) was also observed in April (growth period) which reflected that only availability of water is not suitable for the growth of this species rather optimum temperature is also required that was not available during the

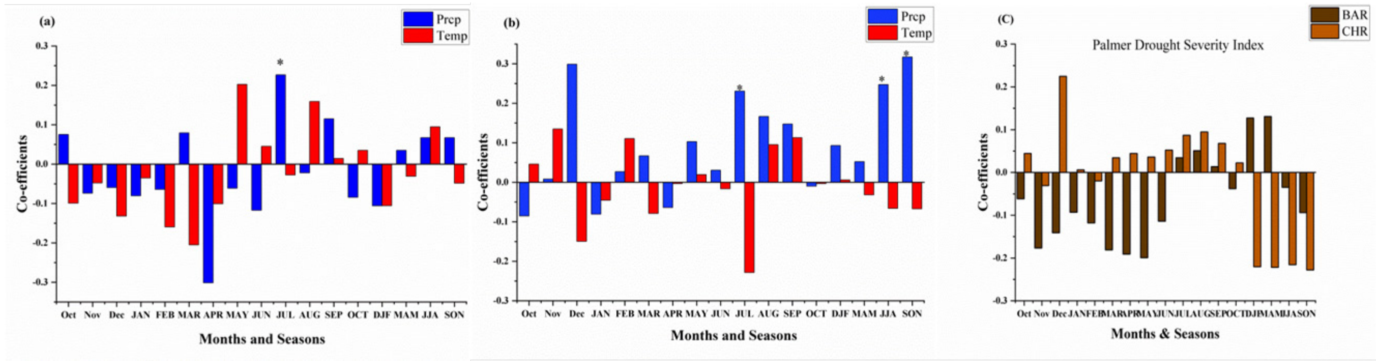

Figure 6: *Correlation coefficient (r) between TRW and monthly meteorological variables (temperature, precipitation and PDSI) from the previous (lower case) and current years (capital letters) (a) Barkan (b) Bomborate. Statistically significant relationships (p<0.05) are indicated by hysteric. Correlations were calculated from October of the year prior to tree-ring growth to October of the current growth year over the common period (1965–2015). DJF, MAM, JJA, SON represent winter, pre-monsoon, monsoon and Autum season accordingly (Asad et al., 2010; Ahmed et al., 2010 Sohar et al., 2017; Ullah et al., 2022)*

growth period. Further, no prominent effect of both temperature as well as precipitation was recorded from the previous year as well as during winter and autum seasons in this area. At the study site of Bomorate, a significant and positive correlation ($r=0.24; p<0.05$) was observed during the month of July (current year) as well as during monsoon ($r=0.25; p<0.05$) and autum season ($r=0.32; p<0.05$) with precipitation. During growth period (Mar-May) both climatic factors were found to contribute their role but effect was non-significant (Figure 5a).

Table 5: *Trend analysis of tree growth of himalayan spruce growing in KPK-pakistan.*

Name of station	Tree ring feature	Z-Value	p-Value (Upward)	p-Value (Down-ward)	Trend
BAR	TRW	0.64	0.26	0.73	No
BOM	TRW	2.46	0.00	0.99	UWT

BAR= Barkan Usheri, BOM= Bomborate, UWT= Upward Trend.

As for as PDSI is concerned, no prominent effects was recorded during previous as well as current growth years for both study sites (Figure 5c).

Discussion

Statistics of the chronology

The climate-growth relationship of a particular site and a specific species is one of the main research subjects in the field of dendroclimatology (Rabbel *et al*., 2018). Therefore, the selection of a sensitive study site and suitable species which can give maximum climatic signals are pre-requisite to establish a good growth-climate model (Sullivan and Csank, 2016). Conifers are considered more sensitive to climate change than the broad-leaved tree species and *Picea smithiana* is considered one of the most suitable tree species for studying the past effects of climate in the region (Khan *et al*., 2008; Ahmed *et al*., 2009, 2010). The dendroclimatic potential of a tree species depends on its tree ring characteristics like correlation with master chronology, mean tree ring width, mean sensitivity, standard deviation, 1st order auto-correlation coefficient, high amount of EPS, SNR and Rbar values, sample depth (Fritts, 1975; Ahmed *et al*., 2010).

Cofecha statistics showed that both the tree ring chronologies scored an acceptable value of correlation with the master chronology and may be used for the study of climate-growth relationship (Wigley *et al*., 1984). The possible reason is good cross-dating of these tree ring series that generated a higher value of correlation. The highest value of correlation coefficient (0.77) with master chronology was recorded in the dry temperate forest area of Bomborate of Kalash valley and these results are in accordance with the findings of Zafar *et al*. (2010) and Ahmad *et al*. (2013) who developed tree ring chronology in *Picea smithiana* growing in the dry temperate climate of Bagrot, Northern area of Pakistan. The mean ring width parameter is an indication of the pattern of growth of a species i.e., a species producing a wider or narrow growth ring. The values of this parameter found in this study for Himalayan Spruce growing in different climatic areas are in accordance with the findings of other researchers like Ahmad and Naqvi (2005) and Ahmad *et al.* (2010) reported mean ring width value 1.05, 1.008,1.001,1.009 of *Picea smithiana* growing in dry temperate and moist temperate areas of Khyber Pakhtunkhwa and Gilgit-Bultistan provinces of Pakistan. *Picea smithiana* from Barkan Usheri, attained the higher value of mean sensitivity (0.23). According to Speer (2010) a tree ring chronology with a mean sensitivity value of about 0.1 is so complacent that the cross-dating of its tree ring series will be very difficult. On contrary, the chronology with a mean sensitivity value of more than 0.4 is sensitively tricky to cross-date. According to Lamarche, 1974 low mean sensitivity does not necessarily indicate the absence of a strong climatic signal in a chronology. Therefore, the chronology possessing the mean sensitivity value of 0.155 from BAR lie in the acceptable range for studying climate-growth relationship in these areas. A similar mean sensitivity value was recorded by Khan *et al.* (2008); Ahmad *et al.* (2010, 2011) and Bargaonkar *et al.* (2009) and Toledo *et al.* (2011) in *Picea smithia.* The statistic of autocorrelation measures the influence of the previous year's growth on the current year's growth of a tree species (Fritts, 1976). This feature scored little bit higher values by both studied tree ring chronologies but are within the range of other studies carried out in Pakistan and neighboring country like India and Nepal (Bhattacharyya *et al.*, 1988). This high value represented that the previous year's growth significantly influencing the current year's growth of Himalayan Spruce in these areas. For the study of a past event, it is generally considered that the low value of autocorrelation is more useful as compared to higher ones that may create problems during the climate-growth relationship, therefore, it was minimized using the filter technique (Zafar *et al.*, 2010). Climate signals in the tree ring series were examined with Rbar, SNR, and EPS values commonly used by the researchers. The Rbar tells the signal strength of the chronology and explores the common signal strength of the series based upon the sample depth (Cook *et al.*, 2000). The SNR is an expression of the strength of the observed common signal among tree ring indices in the essemble (Wigley *et al.*, 1984) and its high value indicated higher climatic signals in the chronology (Fritts, 1976; Zafar *et al.*, 2010). Chronology confidence and strength of the common signal in the chronology is also determined by EPS and a value of 0.85 is considered reasonable but no minimum value is determined to ensure that a chronology is suitable for studying climate-growth relationship in order to reconstruct past climatic factors like temperature, precipitation etc. (Ahmed *et al.*, 2011). By following these features criterion, both the tree chronologies reflected good values of climate signals in their chronologies and showed suitability and reliability for studying the growth response of *Picea smithiana* to climate change. A reliable sample depth of a chronology is another prerequisite for studying climate-growth relationship. According to Speer, 2010 about 20 trees (two cores/ tree) per site or stand can remove the individual tree variability and yield a stand-level variability while Fritts (1976) suggested 12 trees (two cores/tree). In view of this scenario, the chronology developed for Bomborate from Chitral Forest Division showed maximum sample depth while the BAR site chronologies showed low sample depth and needed to increase more sample size with longer tree ring series. It is considered that trees experience years with extreme growth conditions in view of climatic or other impact factors (natural or anthropogenic). These years are called event years and can prompt the development of above-average wide or narrow tree rings (Schweingruber *et al.*, 1990). In this study, the presence of positive and negative pointer years, similarly positive and negative event years in both the chronologies showed that this species is perceiving the climatic change signal and incorporating these signals into their annual growth rings.

Climate data analysis

Tree growth is influenced by both abiotic and biotic factors of the environment. Among abiotic factors, temperature and precipitation are commonly considered the most effective factors (Toledo *et al.*, 2011). In order to examine the impact of climate change on the flora and fauna of a study site, it is very important to determine the climatic changes that have happened in the area. The statistical analysis of climatic data for the both study sites revealed a prominent increase (0.76 & 0.88 °C respectively) in monthly mean temperature and a non-significant increase in precipitation. This increase in temperature at both study sites BAR & BOM is in accordance with the study of Bukhari *et al.* (2019) and Bajwa and Satti (2015) who studied the change in climatic conditions and its impact on conifers in the Galliat forest Division.

Growth- climate relationship

Tree growth is affected by several factors, some of which are specific to its location and age, while others are connected to broader environmental variable like temperature, precipitation and PDSI (Yeh and Wensel, 2000; Adams, 2014). It is commonly considered that precipitation played a vital role and act as a limiting factor in the growth of trees under moist conditions (Khan *et al*., 2022). The temperature along with a suitable supply of water during the growth period are prerequisites for the normal growth of tree species (Pallardy, 2010). Barkan Usheri is situated in the moist temperate forest area of Dir Forest Division, and a positive correlation with precipitation during the month of July (monsoon) followed the findings of Ahmad *et al*. (2009, 2010). As no prominent response to temperature as well as PDSI was recorded during this period, therefore normal trend in growth was observed. Bomborate belong to dry temperate forest areas and it is generally considered that temperature acts as a limiting factor for the growth of coniferous trees but in this location, again the significant role of precipitation was evident i.e., precipitation during the month of July coupled with high temperature is favoring the growth and an upward trend in growth (Zafar *et al*., 2010).

Conclusions and Recommendations

Himalayan Spruce growing in the moist and dry temperate forests of Khyber Pakhtunkhwa has great potential for studying growth-climate relationship. The growth feature of this tree found directly affected by precipitation and seasonal precipitation found more influencial than the individual months as in Bomborate. This study serves as a foundation for short-term growth-climate data to create estimates for long-term growth. In order to get more information about the dendroclimatic potential of Himalayan Spruce, it is recommended to correlate the results of this study with other regional studies. Further, the results of this study could be helpful for scientists and researchers to forecast regional and global climate change by reconstructing past climatic factors and to prepare themselves for transformational adaptation, and find solutions through mitigation.

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Novelty Statement

First study of the region that compared growth dynamic of Himalayan Spruce growing under different climatic conditions.

Author's contribution

Dr.Tanvir Hussain: This is a part of his PhD, planned, executed and drafted the manuscript.
Dr. Kafeel Ahmad: Supervised the PhD research, input valuable comments, corrected manuscript.
Mr.Asif Ali: Helped in manuscript drafting and writing,
Mr. Nazir Ahmad: Sported in data collection, compilation.
Mr.Kamal Khan Kakar: Sported in sample preparation and processing in lab.
Mr. M.Inamullah Khan: Sported in field data, and tree cores sample collection.
Mr. Said Akhtar Khan: Sported in sample preparation and processing in lab.

Generative AI or AI assisted technology statement
The authors declare that no genrative AI was used in the creation of this manuscript.

Conflict of interest
The authors have no conflict of interest.

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