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DENDROCHRONOLOGICAL STUDY OF *ABIES PINDROW* (ROYLE EX D.DON) ROYLE (FIR) AS ASPECT OF TREE GROWTH AND CLIMATE CHANGE ANALYSIS IN HINDU KUSH, NORTHERN PAKISTAN

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Abstract

Climate change has severely affected the moist and dry temperate forests of Hindu Kush region, northern Pakistan, specifically impacting the distribution and growth of the west Himalayan fir, known as *Abies pindrow*. This species, an important representative of the area, is facing significant abiotic stress as a result of rising temperatures and shifting precipitation patterns. We determined whether there is any correlation between the variability of *Abies pindrow* tree rings and the corresponding variability of the climate factors in the Hindu Kush region. Sixty-three tree ring cores were collected from thirty-one trees of *Abies pindrow* and developed a tree ring width chronology (AD 1666–2022) for the Dir Upper, Hindu Kush region, northern Pakistan. Radial growth was correlated with climate factors such as temperature, precipitation, Diurnal temperature range (DTR), and Palmer drought severity index (PDSI) in order to identify the major limiting factor for the tree's growth. Precipitation was found to be the most important and driving element influencing the tree growth of *Abies pindrow*. Precipitation from January to May and winter-spring precipitation had shown significant correlations ($p \leq 0.05$) with the radial growth of *Abies pindrow*. These findings suggest that the sum of precipitation during these periods greatly influences the growth *of Abies pindrow*. In contrast, temperature does not appear to have a strong impact on radial growth. Other factors, such as DTR and PDSI, have shown weak or insignificant correlations with Tree-Ring Width (TRW), except for a significant negative association between August DTR and TRW.

The study findings suggested that the growth of *Abies pindrow* in the study area was more sensitive to precipitation rather than temperature, DTR, and PDSI. These results highlighted the importance of further dendroclimatological research and climate reconstruction utilizing the tree-ring chronology developed in this study. Such investigations can provide valuable insights into the past climate variations and help understand the long-term ecological dynamics of *Abies pindrow* forests.

Key words: Dendroclimatology, *Abies pindrow*, Tree rings, Tree growth, Climate change.

Introduction

Climate change is a severe environmental problem that has an adverse effect on environmental assets, particularly forest ecosystems, floristic diversity, and tree growth (Jandl *et al*., 2019). Many variables, including the plant species, site slopes, soil and climate conditions, biotic and abiotic factors, all have an impact on the total biomass production and efficiency rate of an ecological ecosystem (Kastridis *et al*., 2022). The vascular cambium's rate and length of cell division have a substantial quantitative part in the width of a growth ring (Novak *et al*., 2016). As a result, the relationship of various complex internal as well as external variables, including climate, leads to the development of tree-ring width (Fritts, 2001). Tree rings show how a forest responds to environmental factors and give long-term data on productivity. Global climate change, in particular, increases the intensity, duration, and frequency of extreme weather events (Roibu *et al*., 2020), leading to disastrous flash droughts and floods, under which trees' yearly growth is often negatively impacted (Haavik *et al*., 2015). Biological stresses, pollution, and natural or human disturbances, as well as sudden variations in temperature and precipitation, may have an impact on the wood structure within the various growth rings (Panayotov *et al*., 2013). These structural alterations in the rings of tree aid in the quantification and understanding of the effects of various variables on tree development (Fonti *et al*., 2010). Generally, under optimal growth conditions, the cambium can remain active for almost the entire year (Cufar *et al*., 2013). Nevertheless, because of the unfavorable climate in warm locations, the cambium typically ceases dividing in the summer due to dryness, as well as in the long, dry winter or locations with severely low temperatures (de Lara and Marcati, 2016). Slower growth rates are typically brought on by drought conditions during extremely warm weather, with springtime water deficits being the most common culprit (Waszak *et al*., 2021). The "hydrological" year typically spans 12 months from October of the previous year to September of the current year, and it is commonly employed in tree ring width investigations (e.g. Garfi, 2000; Asad *et al*., 2017a; Luqman *et al*., 2021). Wide tree rings in various species are seen in years with high winter and spring rainfall total values, and the favorable effects of precipitation winter may be attributed to the water being stored in the soil for use over the growth period (Kastridis *et al*., 2022).

Climate-resistant trees adapt to changing climates through their growth, which is influenced by temperature, precipitation, and soil quality. They thrive and expand, showcasing nature's adaptability. This growth demonstrates the delicate balance between climate and flora, enhancing our knowledge of ecological dynamics and the importance of preserving these ecosystems for future generations. The growth ring width has been seen to have a negative relationship with springtime temperatures (Zafar *et al*., 2016). This can be explained the positive correlation between rainfall and development, as well as the aforementioned antagonistic correlation between growth and evapotranspiration processes (Kastridis *et al*., 2022). More specifically, when the ground's large water storage restricts water movement, higher temperatures cause a higher rate of evapotranspiration. Because of this, years with low growth rings are seen when there is a severe drop in precipitation and exceptionally high temperatures, as during the growth period (Mar-Sep), or when there is a decrease in rainfall levels following the growing season in the winter months (Papadopoulos *et al*., 2007). In Pakistan, tree growth records have been frequently employed as a proxy for dating to analyze historical climate variability and evaluate the impact of climate on tree growth in various research studies (Ahmed *et al*., 2011; Zafar *et al*., 2016; Asad *et al*., 2017a; Asad *et al*., 2017b; Zhu *et al*., 2021; Ali *et al*., 2021). In the moist and arid temperate forests of the northern Himalayas in Pakistan, two prominent coniferous tree species namely spruce and fir are found (Ahmad *et al*., 2020; Ali *et al*., 2020). Although having great dendroclimatological potential, Pakistan fir tree rings and climatic elements are only vaguely understood currently. Despite its considerable dendroclimatological potential, there is currently limited understanding of the relationship between climatic variables and the tree rings of fir trees in Pakistan (Ahmed *et al*., 2011). To assess climate change variability, it is vital to enhance our comprehension of the growth-climate interactions within fir forests at various geographical scales.

The aim of this study are to (1) establish a long chronology of tree ring width for the *Abies pindrow* species; (2) explore the primary environmental factors that impact the radial growth of fir pine trees in the Dir Upper, Hindu-Kush, northwestern Pakistan; and (3) assess the relationship between tree ring width and climate variables, including PDSI, DTR, precipitation, and temperature.

Material and Methods

Study area and climate: The study was conducted in the northwestern region of Pakistan, as shown in (Fig. 1). The selected site was the sanger valley of Dir Upper, which crosses the administrative border of the Chitral district, Khyber Pakhtunkhwa, Pakistan. High mountains make up the majority of the Dir Upper terrain, which is the most important mountain range. It extends from northeast to southwest at the Chitral District's northern limits. In the winter, the entire landscape is covered with snow, while the Dir Kohistan mountain range of eastern part of the district is arid, whereas the western region mountains are covered with forests. The study area climate exhibits substantial variations, with the high elevation (glacier region) receiving four times more precipitation than the lower elevations of the valley. The snowline for this region begins between 4800 and 5000 m above sea level (Haserodt, 1996). Whereas the western and central parts of the Hindu Kush endure hot, dry summers and cold, wet, or snowy winters due to western disturbances, the southern Hindu Kush receive increased summer precipitation from the monsoon (Nüsser and Dickoré, 2002). However, rainfall in this area varies with elevation (Kick, 1980).

Analysis of tree-ring data and development of chronology: In the Hindu Kush area of northern Pakistan, *Abies pindrow* (hereafter *A. pindrow*) is a more widespread and dominant species at timber-line and has an extensive range of tolerance (Ahmed *et al*., 2011). *A. pindrow* is a little known species with respect to dendrochronological research in northern Pakistan. It is a high-altitude fir of the Pinaceae family found in northern Pakistan between 2550-3450m a.s.l. altitude at alpine and temperate zones (Ahmed *et al*., 2011). We had selected healthy *A. pindrow* trees in the Sanger Valley of Dir Upper, between 2480 and 2730m a.s.l. close to the upper timberline, with no human interference or fire damage. At a height of approximately 1.37 meters above the ground (breast height), a total of 63 increment cores were extracted from 31 living trees (Table 1). Standard dendrochronological procedures was followed in the analysis of the collected increment cores (Stokes and Smiley, 1968; Fritts, 1976), tree ring cores were air-dried at ambient temperature, fixed, and polished for visual cross-dating using progressively finer sandpaper. A LINTAB 6 measurement system (Rinntech, Heidelberg, Germany) was used to measure the cross-dated series with the year, and the precision of the cross-dating was then confirmed using the COFECHA computer software (Holmes, 1983).

To eliminate biological growth patterns and preserve low-frequency climate signals, the raw ring width data was standardized using the ARSTAN computer program (Cook, 1985). A 90-year cubic smoothing spline function was applied to fit each ring width series, which was then detrended and normalized (Cook and Kairiukstis, 1990). A standard mean chronology was generated for study site by averaging the detrended series. Table 1 provides statistical details for the standard (STD) chronology derived from all the trees. Additionally, several statistical descriptors were computed for the Dir Upper chronology, including the mean inter-series correlation to assess the coherence within the chronology and the mean sensitivity (MS) to quantify the year-to-year variance in tree growth (Fritts, 1976). The standard deviation, average growth-ring width, and first-order autocorrelation coefficient were calculated for the raw chronologies. Additionally, various metrics were determined for the residual data, including EPS (EPS $\leq$ 0.85), signal-to-noise ratio (Snr), and the average correlation between all series (Rbar). Rbar, ranging from 0 to 1, represents the degree of common variance among the series, with a value of 1 indicating complete common variance (Cook & Kairiukstis, 1990). The EPS was employed to assess the accuracy of a theoretical population chronology constructed from a finite-sample chronology with an infinite number of trees. The EPS and Rbar values were computed using a 50-year moving frame with 25-year overlaps, allowing for the estimation of their running values.

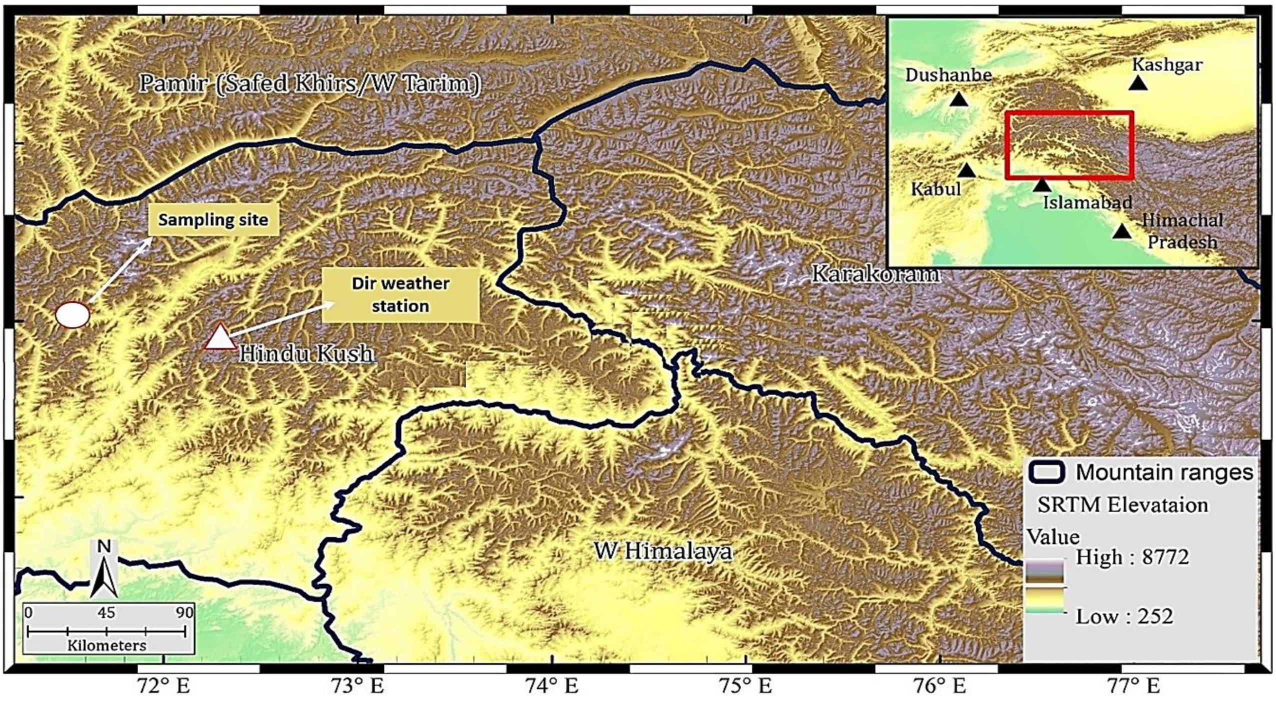

Fig. 1. Location of the Dir weather station and the tree-ring sample site in Hindu Kush, northern Pakistan.

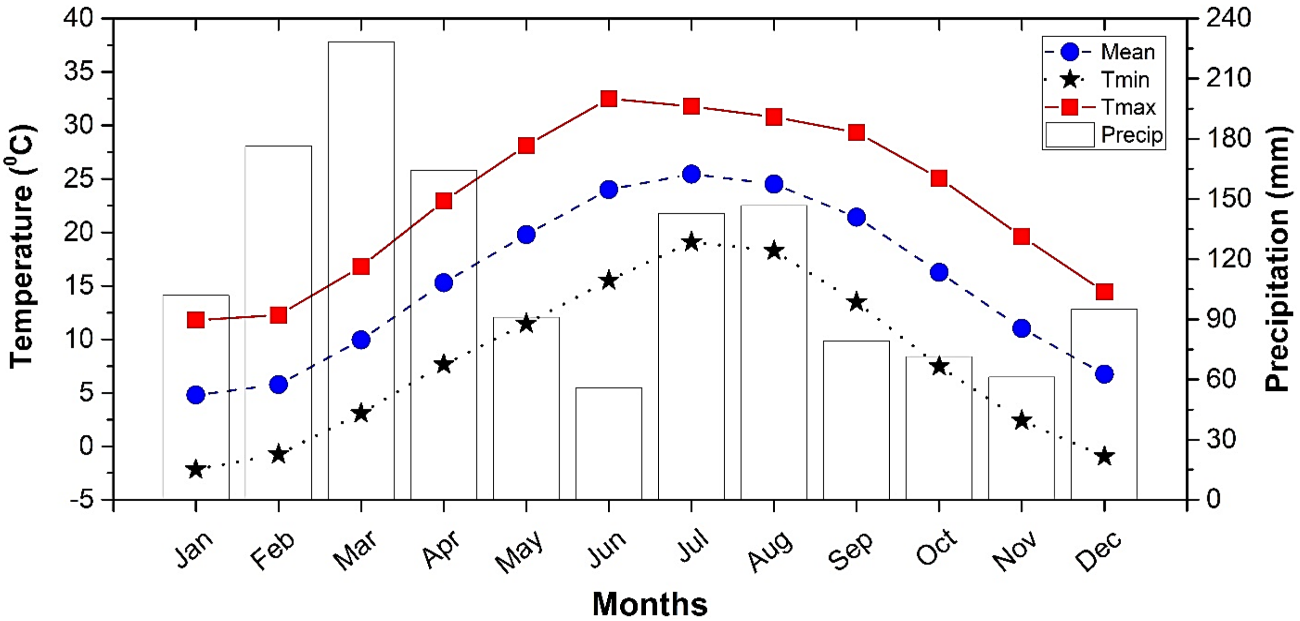

Fig. 2. Climate dia-gram of the Dir weather station data from AD 1967 to 2021.

Climate-growth relationship: The primary climatic data for the study region, such as temperature and precipitation, collected from the weather station that the Pakistan Meteorological Department (PMD) established and ran. On the contrary, the DTR and PDSI data were collected from the closest gridded data (Dai *et al*., 2004). The data series spanning 55 years (AD 1967-2021) was complete, with no missing values. Monthly observations of temperature (mean, maximum, and minimum values) and precipitation sums were available from the Dir instrumental station. These climate station records were utilized to investigate the relationship between climate variables and the tree-ring width chronology. We also take into account the DTR and PDSI data from the same period (AD 1967–2021), since the majority of meteorological stations' data are mostly available from AD 1967.

To examine the relationship between climate factors and tree growth, Pearson correlation analysis was utilized. This statistical approach was employed to assess the degree of correlation between climate variables and the growth patterns of the trees (Heikkinen, 1985). The tree-ring chronology indices were taken into account for this regression as the dependent variable, and the monthly climatic parameters (monthly sum precipitation, Tmean, Tmax, Tmin, DTR, and PDSI), sessional and monthly data from October of the prior year (n-1 year) up to September of the current year, were taken into consideration as the independent variables (Fritts, 1976). Utilizing the CRU TS4.06 gridded datasets for the years 1967–2021, further, investigate and explain the spatial-temporal effect of temperature fluctuation on *A. pindrow* tree development. The KNMI climate-explorer (http://climexp.knmi.nl) was used for the study. Statistical analysis was performed using SPSS-27 software, considering a significance level of $p \leq 0.05$.

Table 1. Information and statistics for tree-ring chronology of the study site.

Study site	Usheri-Dir Upper
Species of tree	*Abies pindrow*
Latitude	35.330°
Longitude	72.043°
Elevation range (m)	2003-2300m
Cores/trees	63/31
Time span	1666-2022
Percent of missing rings (%)	0.013
Series inter-correlation	0.607
Mean sensitivity	0.156
Standard deviation	0.192
Mean-Inter-Series Correlation	0.331
Mean-Intra-Series Correlation	0.719
Signal-to-Noise Ratio (SNR)	28.257
Expressed-Population-Signal (EPS)	0.966

Results and Discussion

Tree ring analyses and standard chronology: During the data evaluating and statistical analysis, two acquired cores from the initial sample of 32 trees were eliminated. These three cores were left out primarily due to the ambiguous tree-ring construction and the inability to connect them to the other cores. In parallel, COFECHA software analysis backed the decision to leave these two cores out of the analyses. Consequently, the ultimate tree sample utilized for the statistical analysis had 31 trees. The master chronology series utilized in the research included the years 1666–2022 (357 years). The average radial of the STD data was determined to be 0.99 mm, with standard deviations for the series inter-correlation and average MS of 0.19, 0.607, and 0.156, respectively. For the common period, the average correlation between all series in the standard (STD) chronology was 0.331. The average correlation within a tree was 0.719, indicating a strong consistency in growth patterns. The signal-to-noise ratio (Snr) was 28.257, highlighting the robustness of the chronology. The EPS of the STD chronology was 0.966, indicating a high level of agreement between the theoretical population chronology and the finite-sample chronology (Table 1). Low-frequency variation (long-term trends) predominates in the research region, as indicated by the low MS values and the comparatively high auto-correlation (AC1) values (Rigling *et al*., 2001). High SNR, EPS and RBAR values signify a definite sensitivity to ambient and stand features. Using a 50-year moving frame with 25-year overlaps allowed us to estimate the running RBAR and EPS values. Similar findings were reported in a previous study conducted by Ullah *et al*., (2022), which examined the growth patterns of the same *Abies pindrow* species in northern Pakistan.

The standard TRW chronology along with sample depth from AD 1666 to 2022 (357 years) for the Dir Upper, Hindu Kush region of northern Pakistan is shown in upper panel of (Fig. 3). Dir Upper (DU) chronology was composed of 63 tree ring cores from 31 trees (Table 1). After AD 1758, the TRW chronology began to shorten as the EPS of the DU chronology was above the 0.85 threshold. The chronology showed the long visible trend in the non-reliable part (AD 1666–1757), whereas the number of cores was 10 (upper panel of Fig. 3). The reliable part of the chronology (EPS > 0.85; AD 1758–2022) showed an increasing trend in AD 1763–1780, 1794–1807, 1821–1832, 1848–1851, 1855–1866, 1872–1876, 1893–1917, 1923–1935, 1942–1948, 1953–1961, 1976–1981, 1991–2000, and 2005–2019 (lower panel of Fig. 3). The lower trend around the mean (0.99) of the chronology was observed in AD 1760–1762, 1770–1775, 1787–1793, 1808–1817, 1833–1844, 1867–1871, 1877–1881, 1936–1941, 1962–1975, and 1982–1990.

The current study's chronology representations are relatively compatible with those published by earlier investigators for northern Pakistan (Ahmed *et al*., 2011; Ahmed *et al*., 2012; Asad *et al*., 2017a; Asad *et al*., 2018; Khan *et al*., 2018). However, the observed values were lower compared to neighboring regions such as the western part of the Himalayas and the Tibetan Plateau (Gou *et al*., 2008; Liang *et al*., 2009a; Shao *et al*., 2010; Dawadi *et al*., 2013), In general, the values of MS and Rbar vary depending on the location. Subalpine-temperate regions tend to exhibit lower MS and Rbar values compared to desert locations (Gou *et al*., 2008; Shao *et al*., 2010). Nevertheless, based on the statistics of the current chronologies, *A. pindrow* is rarely utilized for dendroclimatological investigations, particularly for climate reconstruction.

Pointer years: This study investigated extreme tree-ring width responses using the STD chronology spanning from AD 1758 to 2022 (lower panel of Fig. 3). Based on their average (0.99) and standard deviation (STDV = 0.13), extreme radial growth events were classified as positive (+ive) and negative (-ive) pointer years (Čejková and Kolář, 2009). Over the past 265 years, a total of 41 negative and 33 positive pointer years were identified (Table 2). Using the aforementioned technique of computation, the rate of negative pointer years was higher than the rate of positive pointer years, notably during the second and third decades of the early nineteenth century (AD 1812, 1833, and 1837-1838). Throughout the first two decades of the twenty-first century, no negative pointer was observed. Considering that precipitation which has been demonstrated to be a particularly susceptible factor for tree growth of *A. pindrow* development in the Hindu Kush region. In northern Pakistan, researchers have found a substantial relationship between tree ring width expansion and precipitation levels. Studies have focused in especially on the region's coniferous woods, which are characterized by species such as deodar cedar and blue pine. These trees have been found to be very sensitive to precipitation fluctuations, with larger rings suggesting wetter years and narrower rings indicating dryer years.

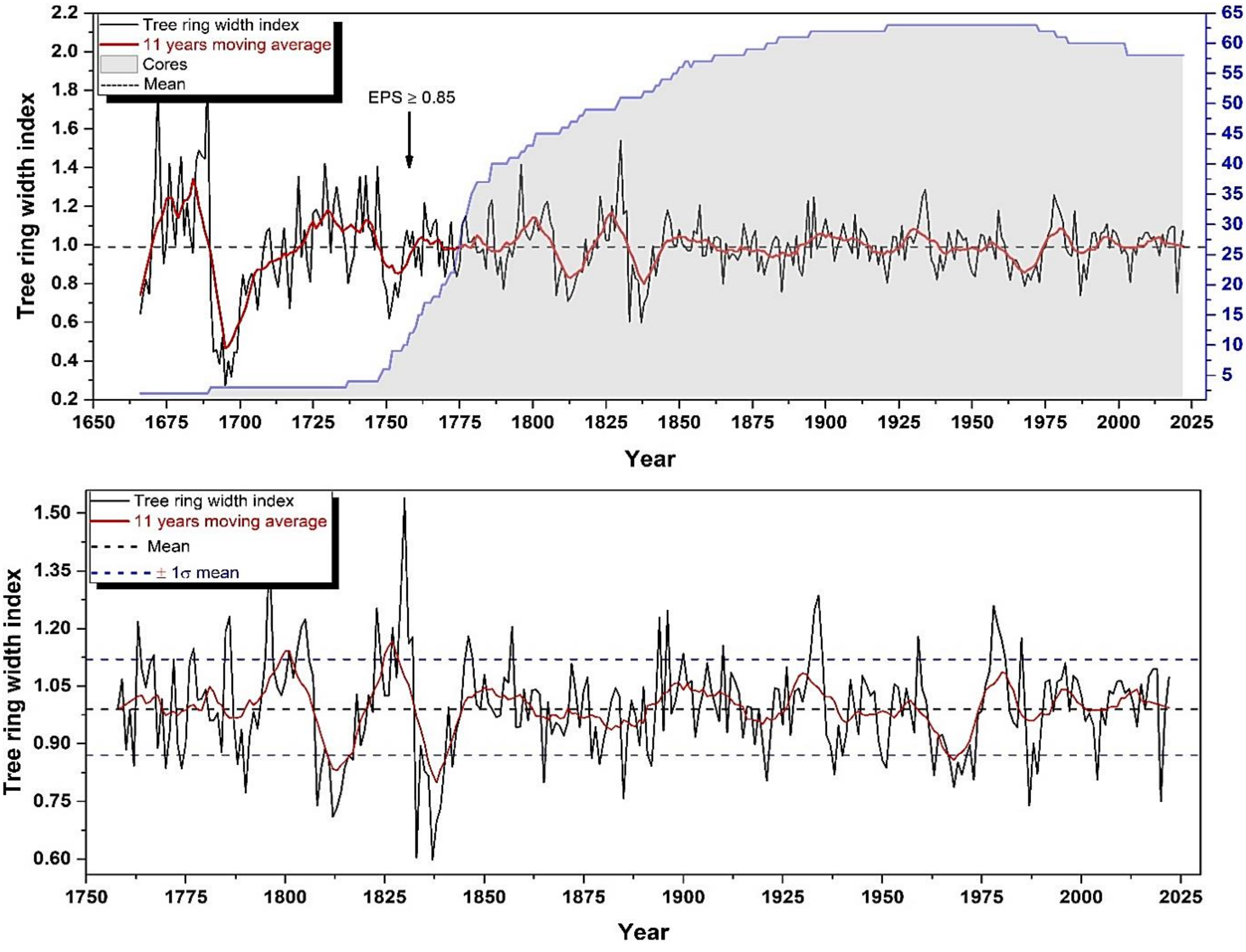

Fig. 3. The figure shows the standard (STD) chronology for Dir Upper, a region in the Hindu Kush area of northern Pakistan. The upper panel displays the STD chronology, while the lower panel presents extremely positive and negative tree-ring width (TRW) values. A long-term mean is indicated by the dashed line, and an 11-year moving average is represented by the bold red line. The tree cores are depicted by the blue curve, and a vertical blue arrow indicates the year where the Expressed Population Signal (EPS) exceeds 0.85.

Table 2. Number of extremely positive and negative pointer years.

Negative Pointer Years	Positive Pointer Year
1762, 1770, 1774, 1788, 1790.	1763, 1767, 1777, 1785-1786, 1795-1796
1808-1809, 1811-1815, 1817, 1833 1835-1840, 1842, 1865, 1877, 1879, 1885, 1892.	1801, 1803-1805, 1823-1824, 1827, 1829-1832, 1846-1847, 1857, 1984, 1896
1921, 1938, 1940, 1950-1951, 1963, 1967-1971, 1973, 1987, 1989.	1900, 1910, 1932-1935, 1959, 1978-1980, and 1985.
2004, 2020	

The positive-pointer years exhibited a strong correlation with higher precipitation and a weak association with temperature, indicating that increased precipitation in the 20th century was beneficial for tree growth in the study area. In a previous study by Esper *et al.* (1995) covering the period from AD 1741 to 1990, 52 negative and 50 unfavorable pointer years were identified, reflecting climatic fluctuations, particularly in temperature. However, the positive effect of CO_2 on tree growth was also observed.

The most favorable pointer year in this study aligns with the exceptional growth conditions observed in the Karakoram region of Pakistan, while tree-ring width variations are indicative of temperature changes (Esper, 2000; Esper *et al*., 2001). Similarly, Asad *et al*., (2017b) reported 33 positive and 28 negative pointer years, with a higher frequency of favorable years compared to unfavorable years, particularly in the twentieth century. These findings strongly corresponded to temperature variations in the Karakoram region, highlighting contrasting trends and/or responses compared to the Hindu Kush region in northern Pakistan.

Relationship between Tree-Ring Growth and Climate: An important tool for evaluating climate change and its effects on natural ecosystems is the growth in tree-ring width. In northern Pakistan, where precipitation is essential to the region's agriculture and economy, tree ring width growth has been used to investigate the relationship between precipitation and tree growth. In the lower panel of Fig. 4, the relationship between tree-ring width and monthly precipitation is depicted. The tree-ring width (TRW) chronology of *A. pindrow* exhibited positive correlations with precipitation in January, February, March, and April (r = 0.25, 0.24, 0.23, and 0.26, respectively). However, no significant association was observed for the remaining months of precipitation. TRW chronology was weakly and insignificantly correlated with PDSI and DTR, except only the month of August showed a negative and significant (r = -0.37; $p \leq 0.01$) correlation with TRW chronology (lower panel of Fig. 4). We also performed the sessional correlation of TRW chronology and climatic factors. TRW chronology was positively and significantly correlated with winter (December-February; r = 0.26, $p \leq 0.01$) and spring (March-May; r = 0.33, $p \leq 0.01$) precipitation, while no sessional correlations were observed with PDSI, temperature, and DTR.

The study also utilized the CRU TS4.06 datasets spanning from AD 1967 to 2021 to examine the spatial correlation between the TRW chronology and gridded mean temperature and precipitation. The comparison revealed significant ($p<0.05$) correlations between the Dir Upper TRW chronology and precipitation in the Hindu Kush, Karakoram, and central-east Himalaya regions (Fig. 5). The relationship became more substantial in the northwest and eventually weakened in the east-to-west direction. A strong ($p<0.05$) association was seen in the Hindu Kush area of Pakistan, the Pamir, the Tarimu Basin, and the east-central Himalayan Region. Insignificant relationships were found between the northeast of Pakistan and the Indian continent.

The findings of this study confirm that precipitation plays a critical role in the forest growth of the DU, Hindu Kush regions in northwestern Pakistan. Specifically, the seasonal precipitation, especially during the winter (Dec-Feb) and spring (March to May) months, showed stronger correlations with tree development compared to individual months. This highlights the significance of seasonal precipitation as the primary limiting environmental factor for forest growth in the DU, Hindu Kush region, rather than temperature, DTR and PDSI. The meteorological station data for northern Pakistan indicate a consistent rise in temperature (Hewitt, 2013; Asad *et al*., 2017a), whereas tree rings and precipitation have a mostly positive association, but their relationship with temperature is insignificant. High temperatures, on the other hand, may increase drought stress by increasing evapotranspiration. In general, higher minimum temperatures at high-elevation coniferous trees affect tree development by reducing root activities (Körner, 1998) tracheid division, and expansion e.g. (Rossi *et al*., 2008). Previous research has established that precipitation plays a crucial role in tree growth and serves as a fundamental factor for climate reconstruction. It provides the necessary physiological support for tree development and offers valuable insights into past climatic conditions.

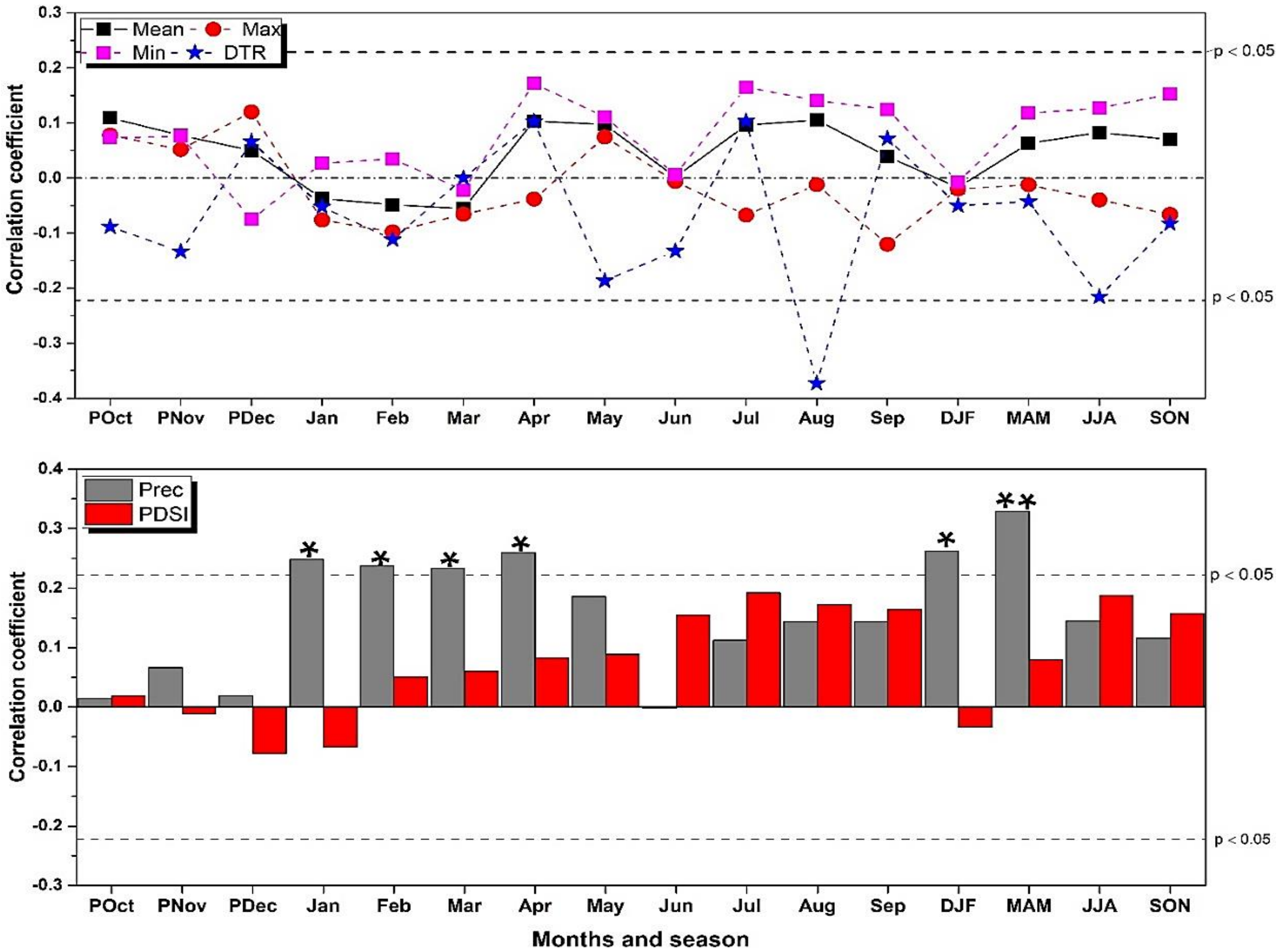

Fig. 4. The upper panel of the figure illustrates the correlation between the Dir Upper chronology and various temperature variables (Tmax, Tmean, Tmin, and DTR). The lower panel represents the relationship between the DU chronology and precipitation, as well as the Palmer Drought Severity Index (PDSI), spanning from October of the previous year to September of the current year. The analysis incorporates seasonal data from the Dir weather station, covering the period from 1967 to 2021. The horizontal dashed line and single asterisk (*) indicate significance at $p<0.05$, while the double asterisk (**) denotes significance at $p<0.01$.

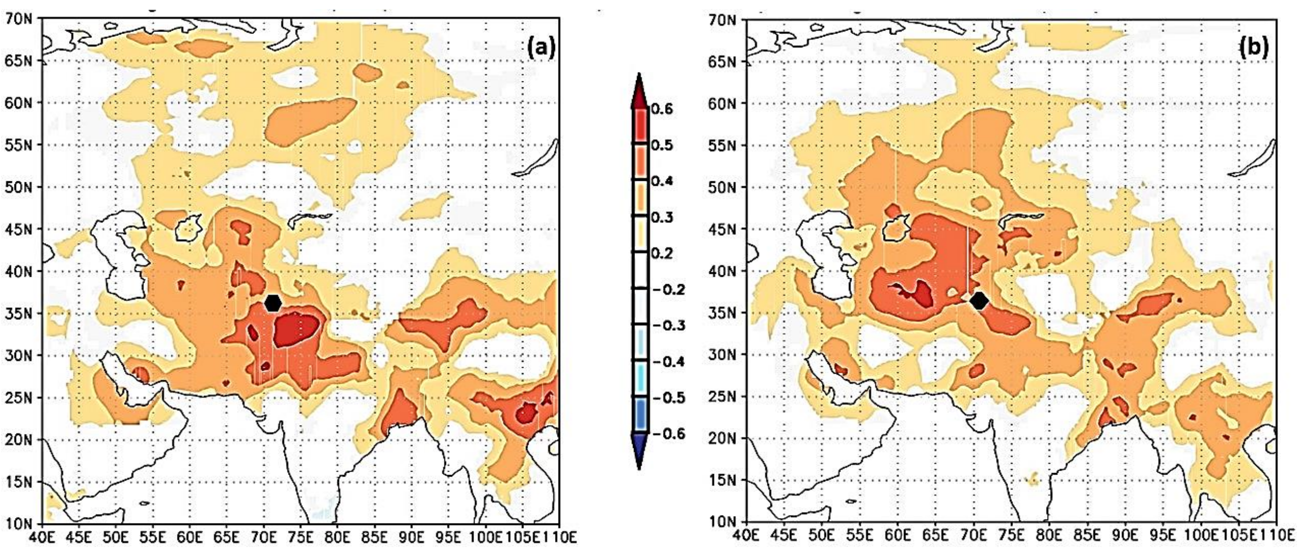

Fig. 5. Spatial correlation of growing season (a) winter (pDec-Feb) (b) spring (Mar-May) mean precipitation with the TRW chronology for the period 1967–2021. The sample site is shown by the black spot.

The positive impact of precipitation on forest growth in northern Pakistan has been documented in several studies, including those conducted by by Ullah *et al*., (2022), Khan *et al*., (2018), Khan *et al*., (2020), and nearby regions by Dawadi *et al*., (2013), Feng *et al*., (2022), Sun & Su (2020), Liang *et al*., (2009b), and Gaire *et al*., (2022). Similarly, Zafar *et al*., (2016) reported that tree growth was adversely associated with summer (JJA) temperature, which might be sensitive to precipitation and is especially noteworthy in tree-lined regions. Temperature and tree-ring width were shown to have positive associations, although tree development at the higher timberline generally responded favorably to summer warmth (Körner, 1998). The difference may reflect the critical importance of species-specific physiological/ecological characteristics in determining the climatic relationship with tree development (Fang *et al*., 2009). Certain studies have indicated that climate-growth correlations can be influenced by species-specific factors (Cook *et al*., 2001). This phenomenon may be observed in areas where environmental gradients are relatively small compared to physiological or ecological gradients specific to each tree species. Khan *et al*., (2013) conducted tree ring research in the Chitral area, northern Pakistan, and revealed that tree ring width growth was closely associated with both winter and summer precipitation levels. The study examined tree rings from C*edrus deodara* trees and discovered that wider rings were related to higher levels of winter precipitation, whereas narrower rings were associated with lower levels of winter precipitation. Similarly, broader rings were related to higher levels of summer precipitation, whereas narrower rings were associated with lower levels of summer precipitation. Similarly, Bajwa *et al*., (2015) discovered similar results in the swat region of northern Pakistan. By analyzing the tree rings of pine trees, the scientists observed a significant connection between the increase in tree ring width and the amount of rainfall during the summer and winter seasons. This study on the relationship between tree ring width and climate factors provides valuable insights into the impact of climate change on the ecosystems and economy of northern Pakistan. By further investigating these associations, researchers can enhance their understanding of the region's climatic patterns and develop practical approaches for managing its natural resources.

Conclusions

We have developed a long chronology of tree-ring width for *A. pindrow* found, at the upper treeline of Dir Upper, located in the north of Pakistan. The association between climatic variables and the tree-ring index showed a strong and significant relationship with precipitation in the winter (December–February) and spring (March–May) seasons ($p \leq 0.01$). The chronology is weekly correlated with monthly and sessional temperatures (maximum, minimum, and minimum), PDSI, and DTR, except that the DTR of August month is significantly and negatively (r = -0.37; $p \leq 0.01$) correlated with the tree-ring index. This showed that the *A. pindrow* forest in the study area was limited to precipitation rather than temperature, DTR, and PDSI. However, favourable growth conditions (positive pointer years) were less common in the late twentieth and early twenty-first centuries, whereas the rate of negative pointer years was higher than the rate of positive pointer years, notably during the second and third decades of the early nineteenth century (AD 1812, 1833, and 1837–1838). These findings demonstrated that the precipitation during the 20th century enhanced *A. pindrow* tree growth. There is a probability that the infrequently utilized species of *A. pindrow* may produce a more reliable model that is exceptional to capture the climate fluctuation for the research location, even if it may not be the best increase for the variance of the model.

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