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# Radial growth, present status and future prospects of west Himalayan fir (*Abies pindrow* Royle) growing in the moist temperate forest of Himalayan mountains of Pakistan

*Zahid Rauf*[1], *Adam Khan*[2*], *Samina Siddiqui*[3], *Sidra Saleem*[4], *Tahir Iqbal*[1], *Safdar Ali Shah*[1], *Nowsherwan Zarif*[1], *Wahiba Iqbal*[1]

[1]*Pakistan Forest Institute, Peshawar, Pakistan*
[2]*Department of Botany, University of Lakki Marwat, Lakki Marwat, Pakistan*
[3]*National Centre of Excellence in Geology, University of Peshawar, Peshawar, Pakistan*
[4]*Department of Botany, Abdul Wali Khan University Mardan, Mardan, Pakistan*

**Corresponding author: adam@ulm.edu.pk*

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**Abstract:** Forests play a significant role for maintaining the biodiversity. In order to manage sustainable forests, tree species history, distribution, and their future prospects are vital. Using standardized quantitative approaches, the age, radial growth, and size class distribution of *Abies pindrow* (Himalayan fir) were determined from three different altitudinal sites (i.e. high, middle, and lower). The results indicate that Himalayan fir growing in the high-altitude site (Ayubia, 2 917 m a.s.l.) of moist temperate forests of the Himalayan mountains showed lower radial growth (0.13 cm) than in the middle (Bara Gali, 2 617 m a.s.l.; radial growth = 0.13 cm) and lower (Kuldana, 2 455 m a.s.l.; radial growth = 0.22 cm) altitude sites. Correlation analysis demonstrated that age showed a significant positive correlation ($P < 0.001$) with diameter at breast height. The tree-ring width chronology (totally 80 core samples) of Himalayan fir was developed from moist temperate forests of Himalayan mountains of Pakistan. At Ayubia site it possesses a long time-span (1703–2020 C.E.), followed by Bara Gali (1862–2020 C.E.) and Kuldana (1864–2020 C.E.). Further, the tree-ring width (TRW) chronology of Ayubia showed a significant positive correlation ($P < 0.05$) with May and June temperature, and a significant negative correlation ($P < 0.05$) with June and October precipitation, indicating that summer temperatures are the key factor for the radial growth of Himalayan fir. For the Kuldana site, the response of TRW chronology to temperature and precipitation was the same, however, it was significant only for June temperature at Bara Gali. The size class distribution of the high-altitude region (Ayubia) showed a higher number of individuals than the lower altitude region, indicating the lowest disturbance conditions. The absence of individuals in the early size classes and the gap in middle and mature size classes indicate a lower regeneration potential and anthropogenic impact. The pointer year analysis indicated that the Bara Gali forest is more sensitive to abnormal climate events than the other sites. Based on the present study, we suggest that proper attention and conservation strategy should be provided to Himalayan fir growing in the moist temperate forests of Pakistan.

**Keywords:** altitude gradient; climate factors; forest structure; growth-climate response; tree-ring chronology

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It is obvious that forests play a significant role in the conservation of ecosystem and species distribution. In addition, they also maintain the moisture content, which supports the growth and development of herbaceous vegetation and regeneration potential (Spies, Franklin 1991). Therefore, the knowledge of forest status and their future prospects are important for the management of natural vegetation (Khan et al. 2021b).

Age and radial growth of a tree are widely used for the understanding of forest cover and management (Worrell, Malcolm 1990a, b). They provide reliable information about the growth and development of a tree, natural disturbances, reduction in radial growth, and their possible causes, which help in sustainable forest management. In addition, different sizes and age classes of a tree are vital for the regeneration potential and forest management (Agren, Zackrisson 1990). The annual ring is a reliable indicator for the understanding of the radial growth and age of a tree (Landis, Peart 2005). A study demonstrated that growth rate is a vital ecophysiological factor that can vary from site to site and even from species to species (Stewart 1986). Though, few researchers advocated that the age of a tree can be determined by visible ring counting (Lusk, Smith 1998; Landis, Peart 2005). Similarly, using simple ring counting the age and radial growth of some selected trees and forests of Pakistan have been explored by a few researchers (Swati 1953; Champion et al.1965; Khan 1968; Sheikh 1985). But their studies were considered overestimated because they did not apply a standardized dendrochronological technique. Furthermore, using standardized tree-ring techniques the age and radial growth of some selected trees and forests have been explored by previous researchers from Pakistan (Ahmed et al. 1990a, b; Ahmed, Sarangzai 1991; Ahmed, Naqvi 2005; Khan et al. 2008; Ahmed et al. 2009; Siddiqui et al. 2013; Iqbal et al. 2020). Similarly, for the understanding of radial growth trends, TRW chronologies of various species have also been developed by a few researchers from Pakistan (Esper et al. 2002, Treydte et al. 2006, Khan et al. 2008; Ahmed et al. 2010b, 2011; Zafar 2013; Zafar et al. 2016; Asad et al. 2017; Khan et al. 2018; 2021a). These studies mostly focused on northern Pakistan. Therefore, for understanding the growth trends and future prospects of the forests of Pakistan with respect to climate change a further in-depth study is acquired from other parts of Pakistan.

The forested area in Pakistan is under anthropogenic pressure. The total remaining forested area in Pakistan is approximately 2.5%, and compared with other countries (20–30%) this ratio is very low (Khan et al. 2021b). Further, the deforestation rate exceeds up to 3% every year (Cronin, Pandya 2009). This destruction rate is the second highest rate in the world. This indicates that if no proper policy for the conservation of natural vegetation were adopted, these ecological and economically important forests would disappear in the near future. Studies offer evidence that the forest structure serves as an essential indicator of previous environmental and anthropogenic disturbance (Timilsin et al. 2007; Gairola et al. 2008; Ahmed et al. 2010a). However, our knowledge of the forest structure and ecosystem is limited because of available scant literature. Few researchers explored the structure and future prospects of some selected forests from Pakistan (Ahmed et al. 1990a, b; Hussain et al. 2010; Khan et al. 2010, 2021b). Even though these studies provide valuable scientific information about forest status, size class distribution, and the socioeconomic impact on forests, they were limited to specific regions and sites. In Pakistan, Himalayan fir is mostly used for timber. In Western Europe, it is often used as an ornamental tree. Its demand is increasing day by day because the wood of this species is used for the construction of stairs, floors, etc. Further, this species is also used for medical purposes, particularly for its anti-inflammatory effect. The species is growing well in the humid region. However, in recent decades, due to illegal cutting the population of this species has significantly decreased in the moist temperate region of the Himalayan mountains (Khan et al. 2016). Therefore, to understand the present status and future prospects of Himalayan fir forests we need pieces of information from across Pakistan. In this aspect the present study is valuable, which focused on the following specific objectives to (*i*) investigate the age, radial growth, and TRW chronology of Himalayan fir growing at different sites of moist temperate forests of Pakistan, (*ii*) determine the present status and future prospects via using the size class diameter distribution, and (*iii*) explore the cause and consequences of anthropogenic pressure on Himalayan fir. We believed that the present study will unlock our understanding of the present status of Himalayan fir, and its possible future challenges.

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## MATERIAL AND METHODS

**Study area.** The sampling sites (Ayubia 34°01'40.40"N, 73°23'39.05"E; Bara Gali 34°04'. 93"N and 73°21'95"E, and Kuldana 33°55'30.81"N and 73°23'44.36'E) of Himalayan fir are located in the moist temperate Himalayan mountains (Figure 1). The elevations of the sampling sites were 2 970 m a.s.l. (Aubia), 2 617 m a.s.l. (Bara Gali), and 2 455 m a.s.l. (Kuldana). The Murree region possesses a temperate climate with cool summers and cold winters. June is the hottest month, while January and February are the coldest months. For June, the mean maximum and minimum temperatures are 26.6 °C and 13.3 °C, respectively (Figure 2). The mean annual rainfall is 1 640 mm, the country's highest rainfall (Archer, Fowler 2008). Soils are predominantly sandy clay, with good moisture content, and rich in organic matter (Khan et al. 2018; Siddiqui 2011). Besides Himalayan fir some other tree species like oak (*Quercus incana)*, chestnut (*Aesculus indica), Olea species (Olea ferruginea)*, blue pine (*Pinus wallichiana*), and chir pine (*Pinus roxburghii)* are the common species which are growing in moist temperate forests of the Himalayan mountains of Pakistan (Aftab, Hickey 2010).

**Sampling and laboratory methods.** Wood/core samples of 5 mm were extracted from the *Himalayan fir* growing at three locations via using an increment borer (Speer 2010). The altitudinal range of our sampling sites was 2 455 m a.s.l. to 2 970 m a.s.l. Two cores samples were extracted from each tree. The diameter of each tree was recorded through diameter at breast height (DBH) measuring tape. The cores were air-dried, glued into the horizontal wooden core fixers, and fine-sanded to get clear rings. The cores were then scanned with the help of a scanner (LA2400 Scanner 3rd generation, Canada) associated with the WinDendro software (density version, 2017) within the range of 1 600 to 2 000 dpi (dots per inch) image resolution depending on the visual quality of core images. Ring-widths were measured to the nearest 0.001 mm from the scanned images and ring decadal files were created as output. The scanned images were subjected to WinDendro, and the ring width of each core sample was determined through proper dendrochronological techniques.

**Age, radial growth rate and diameter size classes.** The age and radial growth of each tree and diameter size classes of each site were determined following the methods given in Ahmed

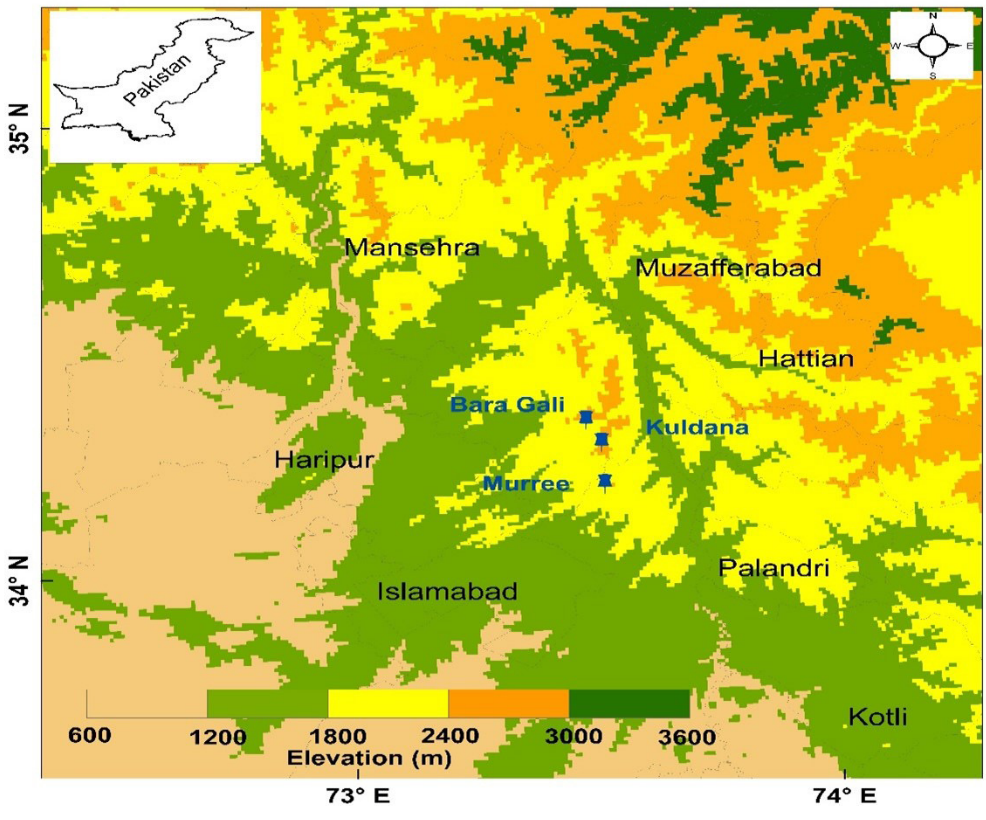


Figure 1. Map of the moist temperate forest of the Himalayan mountains of Pakistan; blue symbols indicate the sampling site of the present study

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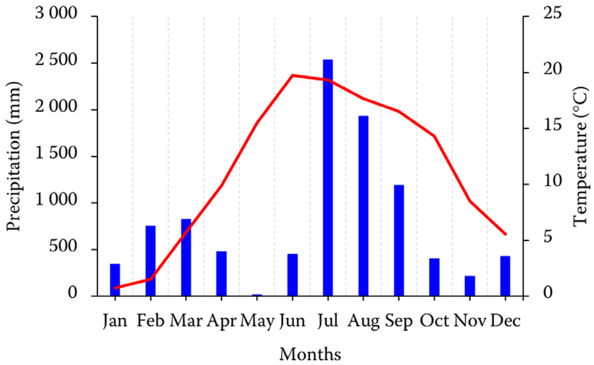


Figure 2. Monthly mean temperature (*T*) and total precipitation (*P*) for the period 1960–2018 from the Muree station of Pakistan

(1984) and Ahmed et al. (2009). Correlations between age and diameter, age and radial growth, and radial growth and diameter were calculated using a linear regression model when taking the radial growth as a dependent variable and age and diameter at breast height (*DBH*) both as independent variables. The regression analysis was carried out for individual sites and overall for composite data of all sites.

**Chronology development and growth characteristics.** A composite file of each raw ring-width series was made. Crossdating of that composite file was done using the TSAP program. The quality of crossdating was checked by the COFECHA program (Holmes 1983; Grissino-Mayer 2001). The raw tree-ring width (TRW) chronologies of each sampling site were developed through the ARSTAN computer program (Cook 1985) by applying 20-year lowpass filter. Series intercorrelation, mean sensitivity and standard deviation were calculated for core samples of all individual sites to assess the crossdating strength, climate sensitivity and climatic information present in the annual growth rings, respectively. During single years, severe environmental and meteorological circumstances may be critical to tree development in average climatic conditions (Neuwirth et al. 2004). To predict the severity of the environment on tree-ring growth we performed the pointer year and the superposed epoch analysis (SEA). An averaged period of previous 5 years and 5 years after the pointer years was used for deviations from the mean ring width index (*RWI*). Randomly chosen 11-year sets from 1 000 bootstrapped sets were applied for the determination of variations using dplR (Bunn 2008).

## RESULTS

**Age, radial growth and correlations among diameter at breast height, age and radial growth.** In this study, the DBH of Himalayan fir from the moist temperate forests of Himalayan mountains was in the range of 24.2 cm to 207 cm, whereas age was in the range of 32 years to 604 years (Table 1). The results indicate that *DBH* and average age significantly increased with the increase of altitude (Table 1). However, Himalayan fir shows slow growth at high altitudes (Ayubia). Further, this species showed high radial growth at the medium altitude (Bara Gali, 2 617 m a.s.l.) compared to the lower altitude site (Kuldana, 2 455 m a.s.l).

The results of the correlation analysis demonstrated that age showed a significant positive correlation with DBH, whereas a significant negative correlation with annual radial growth for all three individual sites (Table 2). No significant correlation was observed between *DBH* and radial growth. The overall correlation of composite data of sampled sites revealed a significant positive correlation ($r^2$ = 0.747, $P$ < 0.001) between *DBH* and age, whereas a significant negative correlation ($r^2$ = 0.747, $P$ < 0.001) were determined for age and radial growth.

**Characteristics of tree-ring width chronologies.** The TRW chronologies (Figure 3) revealed that the growth rate was high from 1850 C.E. to 1700 C.E. A small reduction in the radial growth of Himalayan fir was noted around 1770 C.E. However, a significant reduction in the radial growth of Himalayan fir was observed from 1850 C.E. to 1900 C.E., and 1950 C.E. to 2020 C.E. Overall, in recent decades, reductions in the radial growth rate of Himalayan fir were observed in all sampled sites of this study. This reduction in radial growth rate was higher than the reduction in the $17^{th}$ century. The characteristic features of TRW chronologies of the sampled sites are given in Tables S1–S3 in Electronic Supplementary Material (ESM). The Ayubia site showed the highest interseries correlation ($r^2$ = 0.349), followed by Kuldana ($r^2$ = 0.307) and Bara Gali ($r^2$ = 0.232). The growth ring mean, maximum measurement values and standard deviation (unfiltered) were highest for Bara Gali, followed by Kuldana and Ayubia. The autocorrelation of the Kuldana site was higher ($r^2$ = 0.76), followed by Ayubia ($r^2$ = 0.706) and Bara Gali ($r^2$ = 0.600). The effect of climate change on tree radial development is quantified using the term

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Table 1. Age and annual radial growth of *Abies pindrow* (Himalayan fir) growing in the moist temperate forest of the Himalayan mountains of Pakistan

| Site | Altitude (m a.s.l.) | Diameter range (cm) | Age range (years) | Average age (years) | Average growth (cm·year$^{-1}$) |
|---|---|---|---|---|---|
| Kuldana | 2 455 | 24.2–98.9 | 32–121 | 133 ± 55 | 0.222 |
| Bara Gali | 2 617 | 53.7–145 | 95–388 | 192 ± 63 | 0.235 |
| Ayubia | 2 970 | 48–207 | 48–604 | 347 ± 121 | 0.130 |

Table 2. Correlation and linear regression among age, diameter at breast height, and radial growth of Himalayan fir

| Site | Parameter | No. of core samples ($n$) | Correlation coefficient ($r^2$) | Regression equation | Significance level |
|---|---|---|---|---|---|
| | age/DBH | | 0.689*** | $y = -5.0114x + 7.211$ | S |
| Kuldana | DBH/radial growth | 28 | 0.000 | $y = -0.00375x + 0375$ | NS |
| | age/radial growth | | –0.628*** | $y = 0.0009x + 1.2936$ | S |
| | age/DBH | | 0.644*** | $y = -3.1339x + 4.4956$ | S |
| Bara Gali | DBH/radial growth | 35 | 0.311** | $y = 0.00232 + 0.23201$ | NS |
| | age/radial growth | | –0.502*** | $y = 0.0006x + 1367$ | S |
| | age/DBH | | 0.509*** | $y = -6.4551x + 7.1131$ | S |
| Ayubia | DBH/radial growth | 32 | 0.129 | $y = 0.00129 + 0.16036$ | NS |
| | age/radial growth | | –0.636*** | $y = 0.1281x + 1.4786$ | S |
| | age/DBH | | 0.747*** | $y = -6.743x + 7.633$ | S |
| Overall | DBH/radial growth | 95 | –0.112 | $y = 0.00171x + 0.20855$ | NS |
| | age/radial growth | | –0.699*** | $y = 0.3210x + 1.6791$ | S |

**$P < 0.01$; ***$P < 0.001$; S – significant; NS – non-significant

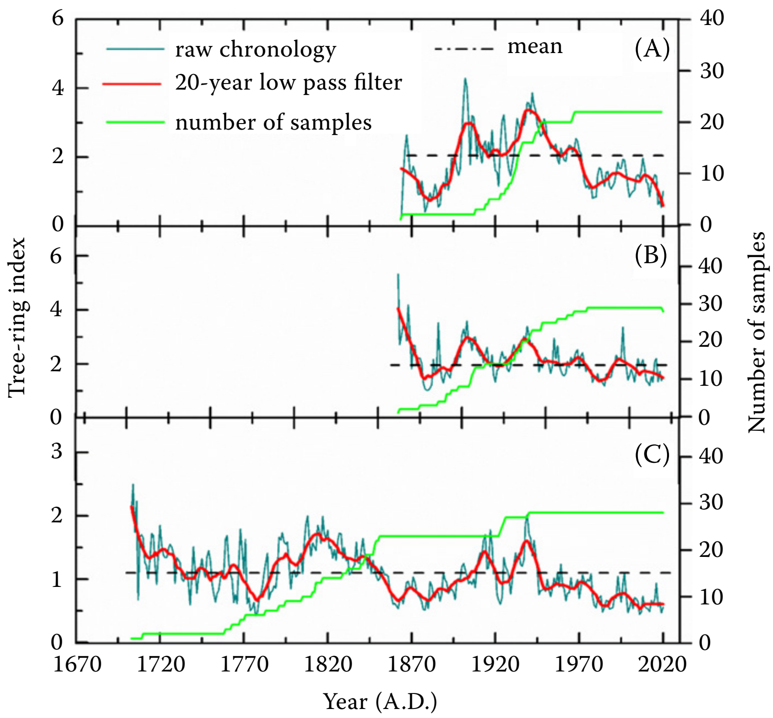


Figure 3. Raw ring-width chronology of Himalayan fir growing at (A) Kuldana, (B) Bara Gali, and (C) Ayubia sites of the moist temperate forest of the Himalayan mountains of Pakistan

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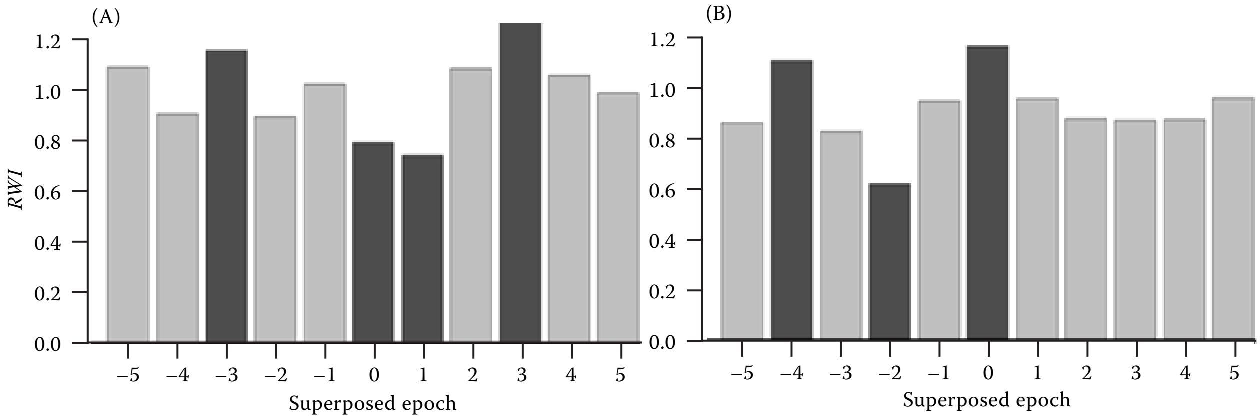


Figure 4. Superposed epoch analysis of (A) negative and (B) positive pointer years from the Ayubia of moist temperate forest of Pakistan

*RWI* – ring width index

"mean sensitivity" (*MS*). There are three levels of *MS*: low (0.10–0.19), moderate (0.20–0.29), and high (0.30 or beyond). Mean sensitivity was higher (*MS* = 0.362) for Bara Gali, followed by Kuldana (*MS* = 0.306) and Ayubia (*MS* = 0.30). The standard deviation was highest for Bara Gali, followed by Ayubia and Kuldana. The autocorrelation was lowest for Ayubia, followed by Kuldana and then Bara Gali.

**Pointer years and superposed epoch analyses.** The positive pointer years are defined as exceptionally wide, and the negative years are defined as exceptionally narrow (Schweingruber et al. 1990) (Table S4 in the ESM). The pointer year analysis is based on the calculation of Neuwirth et al. (2004, 2007). Overall, four negative pointer years (1878, 1886, 1898, 1899) and five positive pointer years (1876, 1902, 1903, 1925, 1935) were detected at the Kuldana site. For Bara Gali site, fifteen negative pointer years (1819, 1820, 1824, 1826, 1833, 1837, 1843, 1844, 1846, 1853, 1854, 1865, 1869, 1870 and 1871) and fourteen positive pointer years (1817, 1822, 1823,1831, 1832, 1841, 1842, 1849, 1851, 1859, 1860, 1866, 1867 and 1868) were observed. Six negative pointer years (1717, 1729, 1738, 1753, 1765, and 1766) and four positive pointer years (1716, 1720, 1749, and 1768) were identified at Ayubia site. In this study, the most extreme positive pointer years (1842 and 1851), and the most extreme negative pointer years (1833 and 1870) were observed at the Bara Gali site. For the Ayubia site, the extreme positive pointer year was 1720, whereas the extreme negative pointer years were 1717 and 1765.

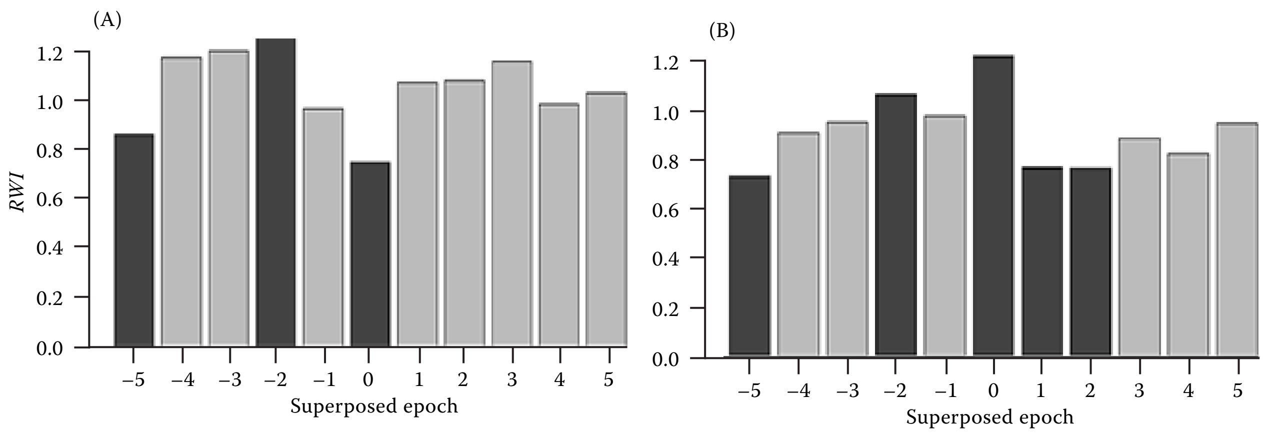


Figure 5. Superposed epoch analysis of (A) negative and (B) positive pointer years from the Bara Gali of moist temperate forest of Pakistan

*RWI* – ring width index

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The superposed epoch analysis (SEA) of the tree-ring index showed a resemblance with the pointer year analysis. The decline in growth, obtained through SEA, showed agreement with the pointer year analysis at the Ayubia site (Figures 4A, 4B). The SEA analysis of the lower elevation site (Bara Gali) demonstrated that there was a significant decline in the growth of the pointer year (Figures 5A, 5B). However, no significant effect on growth was seen after the pointer year. The Kuldana site did not show any extreme positive and negative years.

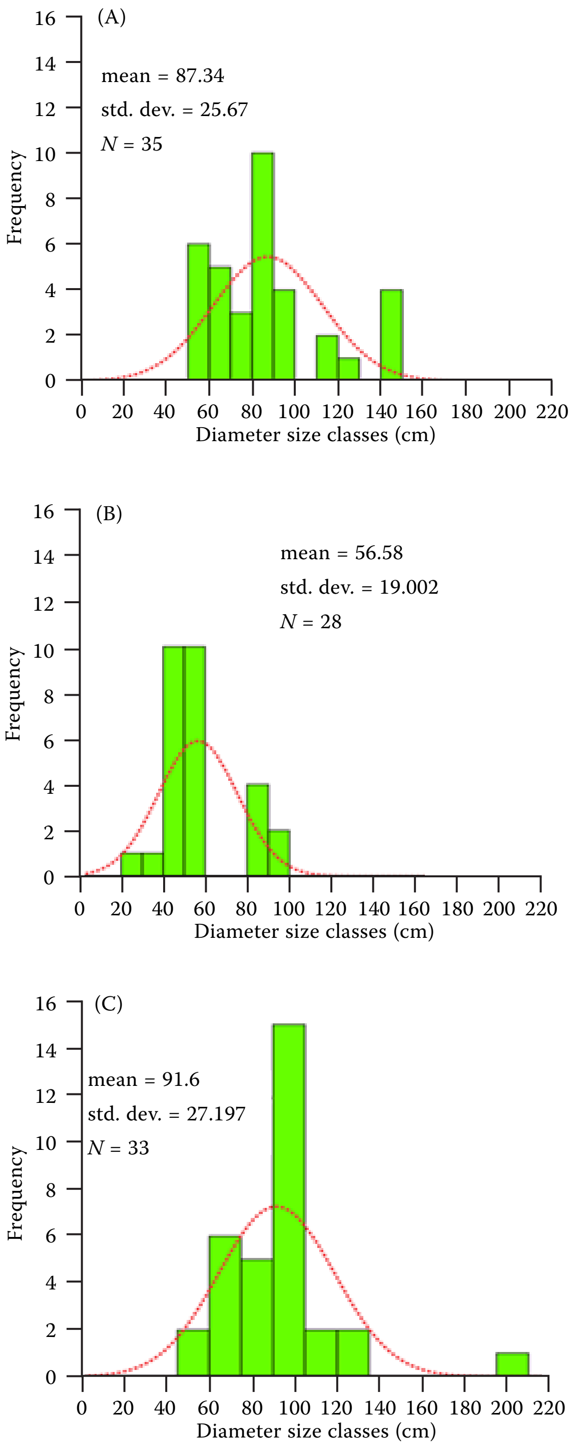


Figure 6. Diameter size class distribution of Himalayan fir growing in three sampling sites from the moist temperature forest of the Himalayan mountain of Pakistan: (A) Bara Gali; (B) Kuldana; (C) Ayubia

**Present status and future trends of forests.** The normal distribution curve of the histogram shows uneven distribution and gap in diameter size classes (Figure 6). The range of diameters at breast height at Bara Gali was 50 cm to 150 cm (Figure 6A). It was from 20 cm to 100 cm at the Kuldana site (Figure 6B), and from 45 cm to 210 cm at the Ayubia site (Figure 6C). The Bara Gali sampling site (Figure 6A) shows the highest individual from 50 cm diameter to 100 cm diameter. Further, a few individuals were recorded from 110 cm to 120 cm and 140 cm to 150 cm. The gap in the early and mature classes indicates a socioeconomic pressure on the forest particularly on Himalayan fir. In the sampling sites, the diameter size classes of Kuldana (Figure 6B) were in the worst condition. In the early size classes of this site, no individual was seen. Moreover, the fewest individuals were seen in the mature size classes. At the Ayubia sampling site, from 50 cm to 130 cm, the number of individuals was slightly better, whereas in early and overmature size classes no individual was seen.

## DISCUSSION

**Age and radial growth of Himalayan fir.** The growth of trees is a natural phenomenon that is mainly limited by environmental factors (Mäkinen et al. 2002; Vacek et al. 2019; Šimůnek et al. 2021), genetic factors (Martín-Benito et al. 2008; Remeš et al. 2015; Vacek et al. 2021), anthropogenic interventions and regime disturbances (Vacek et al. 2017; Štefančík et al. 2018; Cukor et al. 2019). It is evident that slow-growing trees generally reach to a long time span (Bigler 2016). Further, information obtained through TRW chronology plays a significant role in formulating sustainable forest management (Caetano Andrade et al. 2019; Khai et al. 2020), and past climate variation (Ahmed et al. 2010a, b; Khan et al. 2021a). Therefore, this study focused on age, radial growth, and DBH size classes of the understudy region of Pakistan.

Our results indicate that at the highest altitude site (Ayubia) trees showed the highest *DBH* and

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age. However, the radial growth was comparatively lower than at the other sites. The possible reason for the highest *DBH* and age is the lowest anthropogenic disturbance (i.e. environmental and climate factors) in high-altitude regions (Nazareno et al. 2012; Melo et al. 2013). It is evident that trees growing at lower altitudes are more influenced by anthropogenic disturbance than in non-accessible or high-altitude regions (Siddiqui et al. 2013; Khan et al. 2021b). In addition, the lowest radial growth at high altitudes in our study might be due to low temperatures at the peak of the Himalayan mountains. Himalayan fir mostly grows in a pleasant environment, particularly in that region where there is enough water or moisture available in the soil. Further, suitable temperature (moderate temperature) also plays a significant role in the development of Himalayan fir. In addition, the trees growing at the lower altitude site that is exposed to a lower socioeconomic pressure possess higher radial growth than the species growing at a high-altitude region with socioeconomic impact (Liang et al. 2011; He et al. 2013; Yang et al. 2019). In this study, we observed that trees growing in the middle altitude region (Kuldana, 2 455 m a.s.l.) show the highest radial growth compared to the higher altitude (Ayubia, 2 970 m a.s.l.) and lower altitude site (Bara Gali, 2 617 m a.s.l.). There are two possible reasons for these results: (*i*) the species growing at a medium altitude receive enough moisture from the glacier (Lo et al. 2010), (*ii*) the evapotranspiration rate of medium altitude species is comparatively lower than in the lower altitude species (Gao et al. 2017). Studies show that the species growing at a medium altitude show a direct relationship with rainfall and drought compared to the high altitude or timberline (Lo et al. 2010; Gao et al. 2017). However, this statement varies from species to species and even from site to site. For example, in a dry region the species mostly grow at medium altitudes and show marks linked with rainfall and drought (Ahmad et al. 2020). In general, concerning the radial growth with increasing altitude, the positive effect of precipitation in the lowlands changes to the negative effect in mountainous areas (Sidor et al. 2015; Putalová et al. 2019; Vacek et al. 2019). However, this is opposite in the case of temperature. The trees growing at high-altitude sites are mostly more sensitive to temperature than to precipitation. This indicates that moisture conditions increase with the increase of temperature, which is often due to high glaciated mountains. The possible reason is that high temperature melts the glacier at a high altitude, which produces enough moisture with air circulation, increases the photosynthetic activity of trees species, and is responsible for the radial growth of the tree (Khan et al. 2021a).

**Correlation among diameter at breast height, age, and radial growth.** The correlation and regression analysis revealed a significant positive correlation ($P < 0.001$) between *DBH* and age. Similar results were also determined by other researchers from Pakistan (Ahmed 1988a, b). Ahmed and Sarangzai (1991) observed a significant correlation between *DBH* and age nearly at all study area sites. The correlation between *DBH* and radial growth was not significant at any sampling site. This indicates that radial growth does not depend on diameter. It is evident that sometimes the tree possesses a large diameter but the radial growth is very slow (Khan et al. 2021a). The possible reason is the growth of the species in stress environmental conditions or on a steep slope which do not grow faster than in suitable environmental conditions and planned areas. This study also demonstrated that age showed a significant correlation with diameter. Similar results were also observed by other researchers from Pakistan (Siddiqui 2011; Siddiqui et al. 2013). In contrast, no significant correlation between age and diameter was reported by Ahmed et al. (2009). This further determines that the correlation of age and diameter varies from site to site and from species to species. Similarly to our study some other researchers also found the same results (Ahmed 1984, 1988a, b, 1989, 2009; Ahmed, Sarangzai 1991, 1992; Wahab et al. 2008; Ahmed et al. 2010b; Hussain 2013; Siddiqui et al. 2013). From this study, we have anticipated that it is not advisable to predict age or radial growth from the diameter in a multi-aged or sized population.

**Characteristics of raw ring-width chronologies.** The growth trend of TRW chronologies of Himalayan fir from the moist temperate forests of the Himalayan mountains showed resemblance with other studies of Pakistan (Khan et al. 2010, 2018, 2021a). The reduction in the radial growth of Himalayan fir in recent decades particularly after the $19^{th}$ century may be due to the effect of global warming or other environmental phenomena like drought or extremely warm years. The study provides evidence that the radial growth of trees projects to decline in the moist forest due to climate

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change (Rahman et al. 2018). Similar results of the decline in the radial growth of trees in recent years were also noted by other researchers from Pakistan and Afghanistan border (Khan et al. 2008, 2018). However, concern to this theoretical statement, no literature about evidence of the decline in the radial growth of Himalayan fir due to global warming is available from Pakistan.

The Ayubia site had the highest interseries correlation ($r^2$ = 0.349), followed by Kuldana ($r^2$ = 0.307) and Bara Gali ($r^2$ = 0.232). Although Bara Gali is a site at a higher altitude than Kuldana, it had low interseries correlation that may be due to a relatively higher radial growth. High values of autocorrelation were observed for all three sites. The autocorrelation demonstrates the inherent characteristic and climate persistency from a particular year to the next one, i.e. the influence of the previous year's growth on the following year's growth. The autocorrelation was high for Kuldana, followed by Ayubia and Bara Gali. Generally, low autocorrelation values are desirable (Grissino-Mayer 2001). Several studies have previously observed higher autocorrelation values for the pine trees of Pakistan (Ahmed 1989; Ahmed, Naqvi 2005; Ahmed et al. 2012). A high autocorrelation value for Himalayan fir was also reported from the Kashmir region of India (Hughes, Davies 1986). The higher autocorrelation might be due to inter- and intra-competition between species (Ahmed, Ogden 1985) or retaining leaves for several years (Lamarche 1974; Ahmed 1989). Nonetheless, all the reasons mentioned above may be attributed to our autocorrelation values. *MS* determines the impact of climate on tree radial growth. Our results demonstrated the highest *MS* (0.362) for Bara Gali, which is followed by the Kuldana (*MS* = 0.306) and Ayubia (*MS* = 0.30) sampling sites. According to Grissino-Mayer (2001), the *MS* can be categorized as lowest (0.10–0.19), intermediate (0.20–0.29) and high (0.30 or above). It has been demonstrated that a higher mean sensitivity value indicates that the species can absorb the finer variations of the environment compared to lower mean sensitivity (Lamarche 1982). Our results indicated that Himalayan fir from the moist temperate forests of the Himalayan mountains has a potential for dendroclimatic reconstruction. Therefore, proper attention may be paid to the future dendroclimatic study.

**Pointer year and superposed epoch analysis (SEA).** The hot and dry vegetation growth period with low moisture (SPEI) conditions in previous as well as in the current growth years, the cold vegetation periods, and drought conditions may be the factors for the occurrence of negative pointer years. Similarly, opposite conditions to the above are likely to be the prime factors for the occurrence of positive pointer years (Owczarek, Opala 2016; Debel et al. 2021). SEA revealed that there was a negative growth effect of negative pointer years on the subsequent year and more time was required for growth recovery at high altitudes (Ayubia), while no such effect was observed at a low elevation site (Bara Gali). Assigning the specific climate events to every pointer year at each site may be the further point of research in this area.

**Present status and future trends of forests.** Diameter class distribution of trees showed that Himalayan fir growing at the Ayubia site is in better condition than at Kuldana and Bara Gali sites. The normal distribution diameter diagram shows that the regeneration potential was absent at all sampling sites. The possible reason for the absence of individuals in the early-sized classes is overgrazing or anthropogenic pressure (Khan et al. 2021b). Further, the large and mature class gap indicates the harvesting of large and mature trees. The native population in Pakistan's mountains relies on woods for food, shelter, and other necessities (Khan 2011; Siddiqui 2011; Akbar 2013; Hussain 2013; Khan 2017). In addition, as there are no alternative energy sources like gas or proper electricity, so they mostly cut an even number of trees to overcome the fuel problem (Hussain 2013; Khan 2017). Therefore, it is recommended that proper alternative energy sources should be provided to the local community, and the cutting of trees should be banned. Moreover, the seedlings of native trees should be promoted.

## CONCLUSION

In this study the age, radial growth, and future prospects of west Himalayan fir growing in three different localities of moist temperate forests of Himalayan mountains were determined. The results indicate that trees growing at a high-altitude site showed higher age than those at middle and lower altitude sites. The correlation and regression analysis demonstrated a significant relationship between age and *DBH* and age and radial growth. The TRW chronologies revealed a dramatic reduction in the radial growth of Himalayan fir in recent decades,

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which may be associated with climate change or other environmental phenomena. The growth-climate analysis shows that temperature is the key factor for the radial growth of Himalayan fir. Bara Gali showed more resilience to extreme negative climate events, and the Ayubia site is more adaptive to extreme positive climate events. Furthermore, the size class distribution of Himalayan fir demonstrated that the high-altitude site was in better condition than middle and lower altitude sites, reflecting lower anthropogenic disturbance. Though, this study covered three different localities of the Himalayan mountains and did not explore the whole moist temperate forests of Pakistan. Therefore, for a better understanding of the age, radial growth characteristics, and future prospects of Himalayan fir we suggest further in-depth study, covering most part of the Himalayan mountains of Pakistan.

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