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Research Article

Growth response of four dominant conifer species in moist temperate region of Pakistan (Ayubia National Park)

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Abstract

Dendrochronological potential of conifers from Ayubia National Park, Pakistan was determined. A total of four conifer species (*Abies pindrow* (Royle ex D. Don), *Cedrus deodara* (Roxb. ex D. Don), *Pinus wallichiana* A.B. Jacks. and *Taxus baccata* L.) were studied from different elevations. Comparative analysis of DBH-growth rate and DBH-age were performed among the species with maximum age showed by *A. pindrow* of 456 years with 0.01 cm/year growth rate. *P. wallichiana* was found to be fast growing with 0.05 cm/year growth among other species while *C. deodara* trees were having the strongest correlation between their age and DBH values (R^2= 0.9225). Quality of cross dating and accuracy of tree ring measurements was checked by COFECHA. Mean sensitivity of all species ranges from 0.265 to 0.328 with auto-correlations range from 0.562 to 0.712 which specified the dendrochronological significance of these conifers. ARSTAN program was used for autoregressive modeling to remove any possible variance other than climatic disturbance and to standardize the tree ring chronologies. Tree-ring variations were evident among all the cores possessing distinct wide and narrow fluctuations of ring growth with *A. pindrow* (Avg. mean ring width = 1.46 mm) and *T. baccata* (Avg. mean ring width = 1.80 mm). All the conifer species showed good climatic signals in their tree ring measurements and are valuable for the dendroclimatic growth response investigations.

Keywords: arstan; climate; COFECHA; dendrochronology; tree-ring
Abbreviations: Corr., Correlation; DBH, Diameter at breast height; DPL, Dendrochronology Program Library; F, Filtered; msmt, measurement; ITRDB, International Tree Ring Data Bank; UF, Unfiltered

Introduction

Dendrochronology is the study of tree rings which describes the number, characteristics and development patterns. With accurate measurements of tree rings, exact year of ring formation can be determined (Khan *et al.*, 2020). Variations in the climatic and non-climatic variables change the physiology of cells and different patterns of tree ring formation that can be observed. The width of these rings varies with the

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change in environmental conditions (Khan *et al.*, 2018a). The tree rings are formed annually in the temperate regions that help to determine those factors which affect the growth of conifers (Muhammad *et al.*, 2021).

The matching of ring patterns of a number of trees with each other and with trees of the nearby area is called as cross dating. By knowing the patterns of wide and narrow rings and its comparison with temperature and precipitation data, past climatic conditions can be reconstructed under dendroclimatology (Wigley *et al.*, 1987). Zafar *et al.* (2012) found strong relationship between temperature and precipitation and tree growth patterns.

Tree growth is affected by many climatic and non-climatic factors. These factors may enhance the growth or at a time they became limiting factors. These factors are of great importance because their variations are responsible for tree ring patterns which are the basis of dendrochronological studies. Tree species grow well at their climatic regions and are considered as good samples for tree ring studies as compared with the trees present on the margins of their ecological regions. Site selection has also its own importance. Tree ring measurements are also standardized with specific selected computer programs to avoid the maximum chance of errors and to find the exact results (Ahmed *et al.*, 2009; Palmer *et al.*, 2011).

Ayubia National Park is located at 34.1° to 34.38° N latitude and 73.228° to 73.271° E longitude. The hills of the Park Range from North to South near to Abbottabad and along Northwestern end of Murree. Altitude of Ayubia National Park ranges from 1220 m to 2865 m. The highest peaks of the Park are Mirangani 2228 m and Mushkpuri 2865 m. The park is moist temperate area with annual rainfall is above 1500 mm and mean annual temperature is 21° C. Relative humidity of the area is 66% (Khanum and Gilani, 2005). Temperate coniferous forests of Pakistan has great dendrochronological potential and preserved information regarding past stories of precipitation, landslides, glacier movements, climate changes, fire events and seismological effects on these trees (Ahmed *et al.*, 2011). Pakistan is highly vulnerable country to climate change. Global increase in the temperature leads Pakistan towards extreme climatic changes. Change in the temperature, annual precipitation and monsoon variability lead Pakistan towards climatic threats (Chaudhary, 2017). Under the influence of environmental factors, the climatic conditions of Pakistan are continuously changing (Bajwa *et al.*, 2015). These changes depend upon the regional temperature and precipitation episodes. Hence, the tree-ring investigations help to determine these climatic variations of past and can predict future climate (Shah *et al.*, 2019). In conifer forests of Pakistan, many research works were carried out including age and growth rate determination of pines by Muhammad *et al.* (2021), dendrochronological potential determination of gymnosperms from Dir, Swat and Azad Kashmir by Ahmed and Naqvi (2005); Khan *et al.* (2008); Ahmed *et al.* (2009) and Khan (2011). Similarly, Wahab (2011) worked on conifers from Northern areas of Pakistan and estimated their growth rates. Khan *et al.* (2013) covered the aspects of wild fire, hydrology, past climates etc. and also developed tree-ring chronologies for forest management. The present study was planned with the following objectives: (1) To determine age and growth rates of selected conifers: (2) To perform regression analysis between age/ growth/ diameter; (3) To develop tree-ring width chronologies and their interpretation. (4) To estimate the dendrochronological potential of selected conifer species of Ayubia National Park, Northern Pakistan.

Materials and Methods

Samples collection and preparation

Dendrochronological studies aimed to find the effects of various ecological and environmental factors on trees. Climatic factors on high altitudes have more effects on trees than on lower levels (LaMarche, 1982). Healthy, erect and unbranched trees were selected for sampling in 2021. Swedish Increment Borers were the major instruments used. Highly damaged cores which were not suitable for analysis were discarded. In GPS locations geographical coordinates of the trees were noted (Wahab *et al.*, 2008) as given in Table 1 and represented in Figure 1. Packing and tagging of the cores needed due care as a slight damage may led to loss of a useful data (Hart and Mayer, 2008). The cores were air dried. After drying process, they were transferred to wooden frames for their sanding and proper observations. With the help of glue, the cores were fixed on wooden frames and tapped properly to prevent from disturbance.

Table 1. GPS coordinates of conifer species from Ayubia National Park

Tree species	Tree sample	GPS	
		N	E
Abies pindrow (Royle ex D. Don)	Ap3	34.06342	73.41854
	Ap9	34.06319	73.41777
	Ap10	34.06312	73.41662
	Ap16	34.04212	73.41596
	Ap18	34.04183	73.41624
	Ap24	34.05726	73.41765
	Ap25	34.05676	73.41706
Cedrus deodara (Roxb. ex D. Don)	Cd1	34.06354	73.41873
	Cd2	34.06348	73.41856
	Cd4	34.06340	73.41836
	Cd6	34.06330	73.41832
	Cd7	34.06347	73.41856
Pinus wallichiana A.B. Jacks.	Pw11	34.06295	73.41793
	Pw19	34.06299	73.41620
	Pw20	34.04036	73.41686
	Pw21	34.04019	73.41733
	Pw23	34.04004	73.41790
	Pw26	34.05948	73.41912
	Pw27	34.05916	73.41997
Taxus baccata L.	Tb5	34.06337	73.41826
	Tb12	34.04294	73.41548
	Tb13	34.04305	73.41552
	Tb14	34.04317	73.41553
	Tb15	34.04272	73.41575

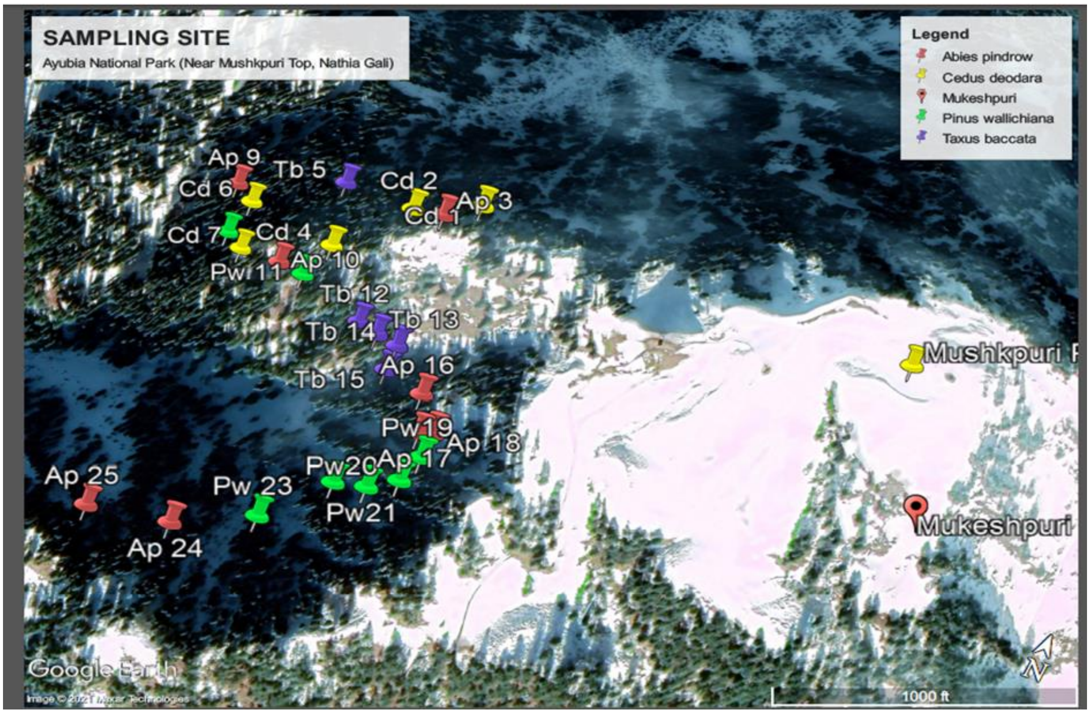


Figure 1. Map of GPS coordinates and exact location of conifers in Ayubia National Park

Measurement

Tree-ring cores were measured after sanding method was applied to make tree rings visible clearly. Then cores were scoured by hand with the help of sand papers to make surface clearer and after that core were polished for fine observation (Stokes and Smiley, 1996; Arnott, 2008). After final preparation of the cores, they were visually observed. Cores were observed on the parameters of insect attack, degraded cores, fire scars and tilted rings. Velmex Measuring System TA402H1 was used for the cross dating and age determination of the cores. Measuring J2X software was used for the formation of series of tree ring measurements. It arranged the data of measurements in decadal format which was the most general format used by all programs in DPL. These files were used for further analysis.

Statistical analysis

COFECHA computer program was used to check the quality of cross dating and measurement accuracy. It also assessed the quality of measurement. This program also identified the outlier ring measurements in the form of flagged rings. These flagged rings were basically the anomalous ring patterns due to local injury or unclear ring boundaries. COFECHA does not involve in the acceptance or rejection of the measurements. This program took a master series from measurements with maximum age and performed correlation with rest. The final selection of the series to be accepted always lies with the dendrochronologist. COFECHA used the Tucson format, established by ITRDB and most commonly used format for tree ring measurements. Statistical values of each decadal segment of individual series and combine analysis of standard deviation, auto-correlations and mean sensitivity of all series and total or mean of statistical values was also provided by this program (Grissino-Mayer, 2001).

ARSTAN stands for autoregressive standardization. It was developed by Dr. Edward R. Cook. By running the software it provided different chronologies of the tree ring series analysis. Hugershoff curve fits were selected for the analysis to show. Four different types of chronologies were obtained. These were ring width chronology, standard chronology, residual chronology and arstan chronology (Cook, 1985).

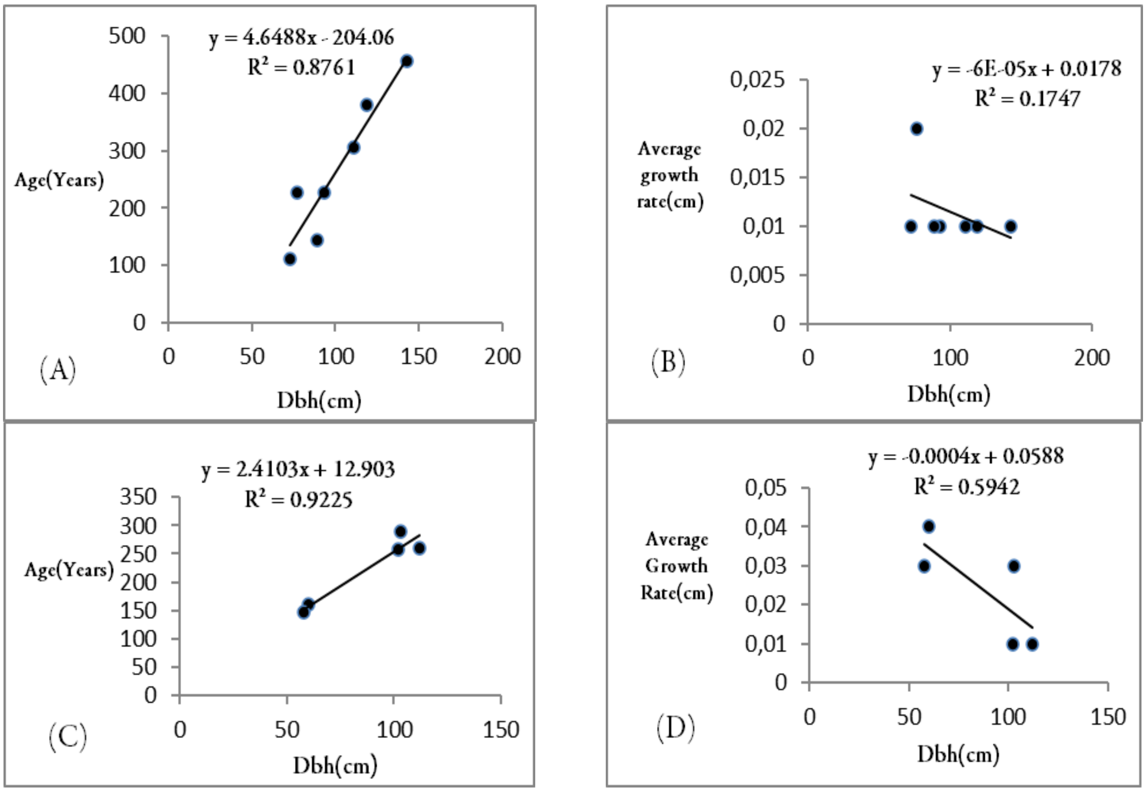
Results

Age and growth rate determination

Age and growth rate studies were carried out on four conifer species *A. pindrow*, *C. deodara*, *P. wallichiana* and *T. baccata*. The mean average growth rates of these species were found to be 0.01 cm, 0.02 cm, 0.03 cm and 0.02 cm respectively as shown in Table 2. A wide range of diameter was observed with minimum 53 cm and maximum of 143 cm. Among all four conifer species, the minimum estimated age was found to be 70 years of *T. baccata* and the maximum estimated age to be 456 years of *A. pindrow*. Correlation analysis was performed between DBH and age and growth rate and DBH of all four species. The DBH and age were found out to be positively correlated (Highest R^2 value = 0.9225, Lowest R^2 value = 0.5509) while growth rate and DBH were not strongly correlated (Highest R^2 Value = 0.5942, Lowest R^2 value = 0.0301) as shown in Figure 2(A-H).

Table 2. Tree cores, mean average growth, DBH and estimated age of four conifer species in Ayubia National Park, Pakistan

Parameters	*Abies pindrow*	*Cedrus deodara*	*Pinus wallichiana*	*Taxus baccata*
No. of Tree / Cores	7 / 14	5 / 10	7 / 14	5 / 10
Mean average growth (cm/year)	0.01	0.02	0.03	0.02
Diameter at breast height (DBH) range (cm)	73-143	58-112	53-128	67-122
Estimated age range (Years)	111-456	146-289	174-273	70-346



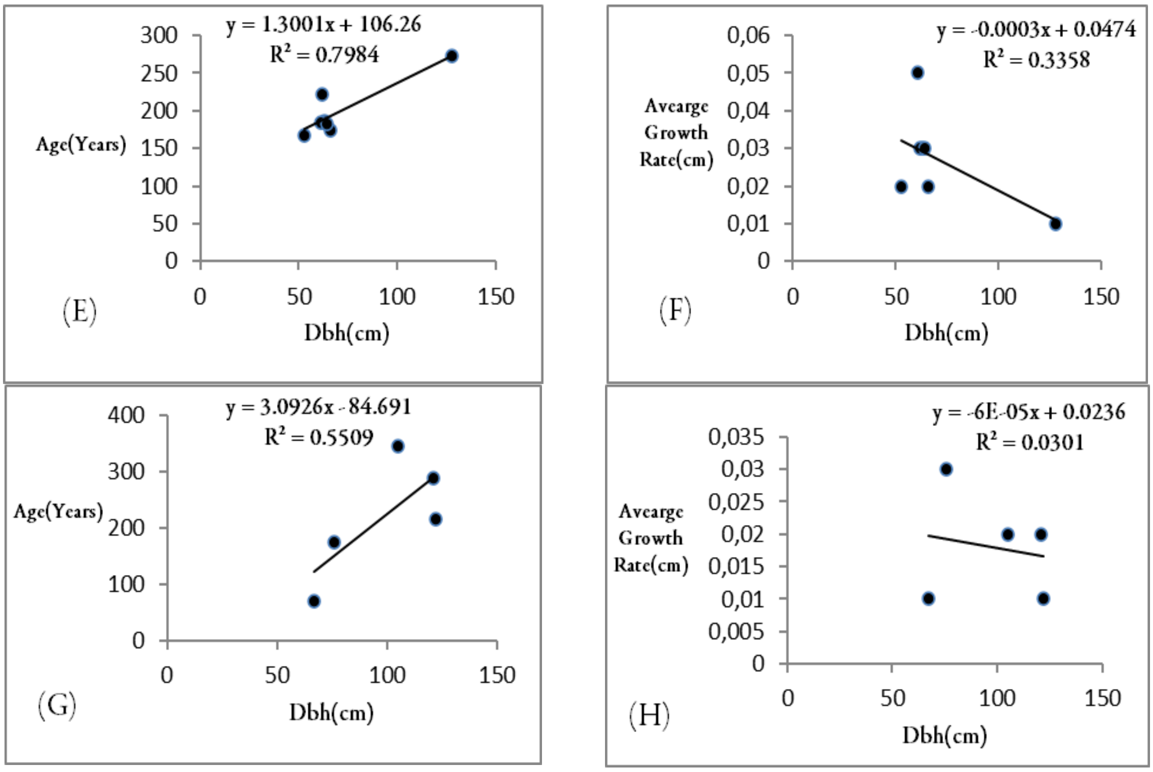


Figure 2. (A-H): Correlation between age and DBH, growth rate and DBH of *A. pindrow* (A, B), *C. deodara* (C, D), *P. wallichiana* (E, F) and *T. baccata* (G, H)

Chronology development and statistics

Table 3 summarizes the statistical values generated by the computer program COFECHA for the four species of the study site. The value of mean sensitivity is the measure of relative change in the ring width from one year to the next year in a series. The average mean sensitivity of *A. pindrow* was 0.265. Autocorrelation value measures the influence of previous year's growth on the current year's growth of trees and this value also does not provide any significant information about the climate reconstruction. This value generally varies from 0.3 to 0.8 and it is species and site specific. Autocorrelation value of *A. pindrow* was 0.712. Measurement of strength of common signals in a tree ring series is known as correlations with master dating series. This value is useful in determination of the reliability of the any chronology. This statistical value does not have any relationship with climatic reconstruction. The values of correlations vary from site to site and species to species. The correlation value of *A. pindrow* with master dating series was 0.033. The national tree of Pakistan showed mean sensitivity of 0.271. The autocorrelation value of tree ring data of *C. deodara* was observed to be 0.562 and it showed correlations with master dating series of 0.065. The mean sensitivity value of *P. wallichiana* was 0.308. While the autocorrelation value was 0.691 and correlation with master dating series was 0.135. It showed maximum mean sensitivity value among all four tree species from Ayubia National Park which was 0.328. Autocorrelations observed was 0.694 and the value of correlations with master dating series for *T. baccata* was 0.001.

Tree ring data files of the Measure J2X were run in this program. Four types of chronologies (Raw chronology, Standard chronology, Residual chronology and Arstan chronology) were produced. Raw chronology does not involve any standardization rather these are just the averaged tree ring measurements. To remove the any possible variance other than the climatic disturbance the curve fitting mode was used which detrended the samples and provided with the standard chronology. Autoregressive modeling was used which standardized the tree ring measurements statistically and remove autocorrelations to provide residual chronology. To identify the common signals in the series of tree ring measurements pooled autoregression was performed with residual chronology. It provided the Arstan version of chronology.

Table 3. COFECHA Statistics of four conifer species in Ayubia National Park, Pakistan

Name of species	Min-max age	Corr. with master	Mean msmt	Max. msmt		Std. deviation		Auto correlation		Mean sensitivity
				UF	F	UF	F	UF	F	
Abies pindrow	63-213	0.033	1.40	7.77	1.64	0.808	0.324	0.712	-0.005	0.265
Cedrus deodara	39-145	0.065	2.07	8.92	2.65	0.844	0.356	0.562	0.002	0.271
Pinus wallichiana	26-93	0.135	2.99	13.89	1.87	1.693	0.409	0.691	0.012	0.308
Taxus baccata	44-107	0.001	1.80	7.97	3.96	0.980	0.379	0.694	0.021	0.328

Tree-ring chronologies were built for the 4 species of the study area. The chronology of *A. pindrow* spanned over 213 years (1809-2021 AD) having mean index of 1.122, 0.968, 0.980 and 0.980 of raw, standard, residual and arstan chronology respectively (Figure 3). The chronology of *C. deodara* extended over 145 years (1877-2021 AD) having mean index of 1.655, 0.973, 0.979 and 0.979 of raw, standard, residual and arstan chronology respectively (Figure 4). Similarly, chronology of *P. wallichiana* spanning 93 years (1929-2021 AD) with 2.865, 0.982, 0.984 and 0.997 mean indices of raw, standard, residual and arstan chronology respectively (Figure 5). *T. baccata* chronology spanned over 107 years (1915-2021 AD) having mean indices 1.842, 0.967, 0.969 and 0.983 of raw, standard, residual and arstan chronologies respectively (Figure 6). The set of statistical values produced by ARSTAN for various chronologies is presented in Table 4. Distinct years of narrow rings representing stress zones and the years having wide rings showing positive growth rate as evident from the chronologies are given below.

Abies pindrow (Royle ex D. Don)

Raw Chronology is showing narrow rings in the years of 1875-1882, 1886-1900, 1925-1934, 1969-2020 AD and wide rings in the years of 1825-1832, 1840-1860, 1901-1905 and 1945-1952 AD. According to standard chronology, 1830-1845, 1868-1874, 1885-1900, 1910-1940, 1990-2003, 2011-2016 AD are the years of narrow rings while 1850-1860, 1945-1955 AD are the years of wide rings. Residual chronology is showing narrow rings in the years of 1830-1850, 1868-1874, 1885-1891, 1896-1897, 1911-1940, 1990-2000, 2010-2016 AD and wide rings in the years of 1851-1861, 1903-1906 and 2003-2005 AD. The arstan chronology is having narrow rings in the years of 1832-1850, 1869-1874, 1885-1900, 1910-1940, 1967-1970, 1980-1984, 1993-2002, 2011-2017 AD and wide rings in the years of 1851-1868, 1881-1884, 1901-1906, 1941-1948, 1985-1991, 2003-2005 AD.

Cedrus deodara (Roxb. ex D. Don)

Raw Chronology is showing narrow rings in the years of 1880-1890, 1900-1975 AD and wide rings in the years of 1890-1896, 1975-2000, and 2005-2020 AD. According to standard chronology, 1900-1918, 1936-1948, 1996-2007 AD are the years of narrow rings while 1930-1932, 1964-1978, 1987-1995 AD are the years of wide rings. Residual chronology is showing narrow rings in the years of 1900-1914, 1936-1944, 1996-2002 AD and wide rings in the years of 1886-1894, 1963-1967 AD. The arstan chronology is having narrow rings in the years of 1878-1881, 1914-1918, 1924-1929, 1937-1945, 1956-1960, 1996-2002 AD and wide rings in the years of 1886-1894, 1945-1950, 1962-1968, and 2015-2019 AD.

Pinus wallichiana A.B. Jacks.

Raw Chronology is showing narrow rings in the years of 1928-1936, 1945-1949, 1983-1991, 1994-2003, 2008-2020 AD and wide rings in the years of 1937-1942, 1961-1976, and 2004-2007 AD. According to standard chronology, 1929-1930, 1941-1942, 1943-1949, 1961-1965, 1982-1990, 1994-2002, 2010-2018 AD are the years of narrow rings while 1938-1940, 1967-1974, 2004-2008 AD are the years of wide rings. Residual chronology is showing narrow rings in the years of 1938-1940, 1942-1944, 1960-1962, 1976-1980, 1982-1986, 1994-2000, 2008-2012 AD and wide rings in the years of 1948-1951, 1965-1970, 2002-2006, and 2019-2020 AD. The arstan chronology is having narrow rings in the years of 1936-1938, 1962-1964, 1978-1990, 1994-2001, 2012-2018 AD and wide rings in the years of 1930-1932, 1948-1950, 1953-1956, 1958-1960, 1965-1972, 2002-2008 AD.

Taxus baccata L.

Raw Chronology is showing narrow rings in the years of 1916-1918, 1942-1944, 1990-2020 AD and wide rings in the years of 1925-1928, 1930-1938, and 1945-1970 AD. According to standard chronology, 1920-1930, 1940-1945, 1950-1960, 1965-1980, 1995-2021 AD are the years of narrow rings while 1915-1920, 1931-1938, 1946-1949, 1985-1994 AD are the years of wide rings. Residual chronology is showing narrow rings in the years of 1915-1925, 1938-1950, 1955-1960, 1965-1975, 2000-2015 AD and wide rings in the years of 1930-1937, 1961-1964, 1976-1985, and 1990-1999 AD. The arstan chronology is having narrow rings in the years of 1915-1930, 1940-1960, 1970-1980, 2000-2015 AD and wide rings in the years of 1931-1938, 1962-1968, and 1981-1999 AD.

Table 4. Statistics of Arstan chronologies of four conifer species of the study site

Conifer Species	Chronology	Mean Index	Standard deviation	Skewness coefficient	Kurtosis coefficient	Mean sensitivity	Serial Correlation
Abies pindrow	Raw	1.122	0.338	1.207	4.696	0.159	0.661
	Standard	0.968	0.166	0.707	4.636	0.135	0.362
	Residual	0.980	0.144	0.510	4.703	0.151	-0.096
	Arstan	0.980	0.177	0.284	3.998	0.115	0.588
Cedrus deodara	Raw	1.655	0.645	1.045	3.174	0.145	0.868
	Standard	0.973	0.145	0.002	3.173	0.133	0.396
	Residual	0.979	0.128	0.117	3.266	0.149	0.007
	Arstan	0.979	0.133	0.200	3.163	0.130	0.266
Pinus wallichiana	Raw	2.865	1.021	1.363	4.852	0.192	0.691
	Standard	0.982	0.202	1.104	4.611	0.166	0.296
	Residual	0.984	0.182	0.623	4.782	0.190	-0.133
	Arstan	0.997	0.253	1.115	4.949	0.143	0.656
Taxus baccata	Raw	1.842	0.705	1.109	4.305	0.191	0.704
	Standard	0.967	0.235	3.700	28.246	0.171	0.227
	Residual	0.969	0.202	1.896	16.728	0.172	-0.130
	Arstan	0.983	0.260	1.861	12.507	0.135	0.562

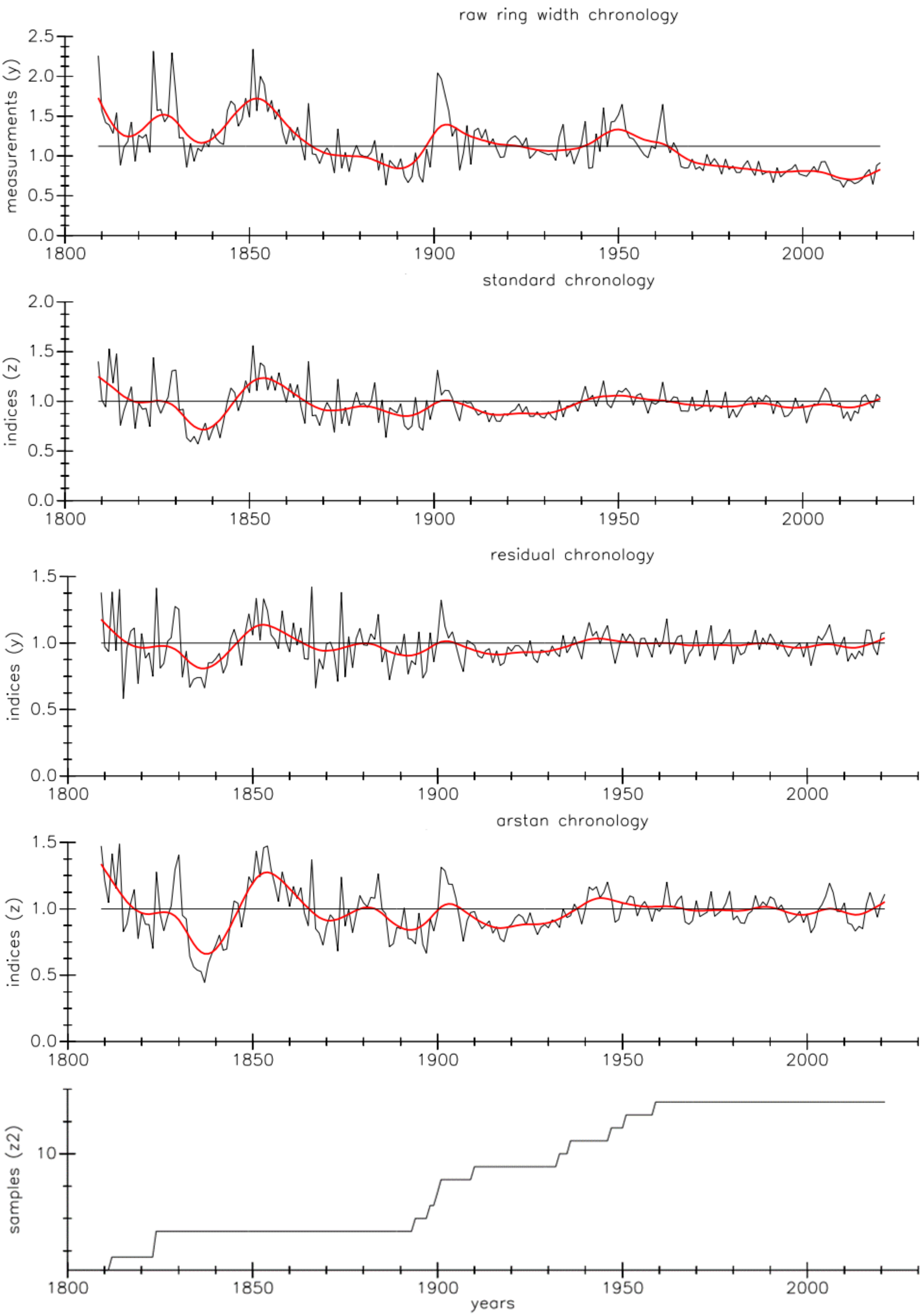


Figure 3. Chronologies (raw, standard, residual and arstan) and sample depth of *A. pindrow* from Ayubia National Park, Pakistan

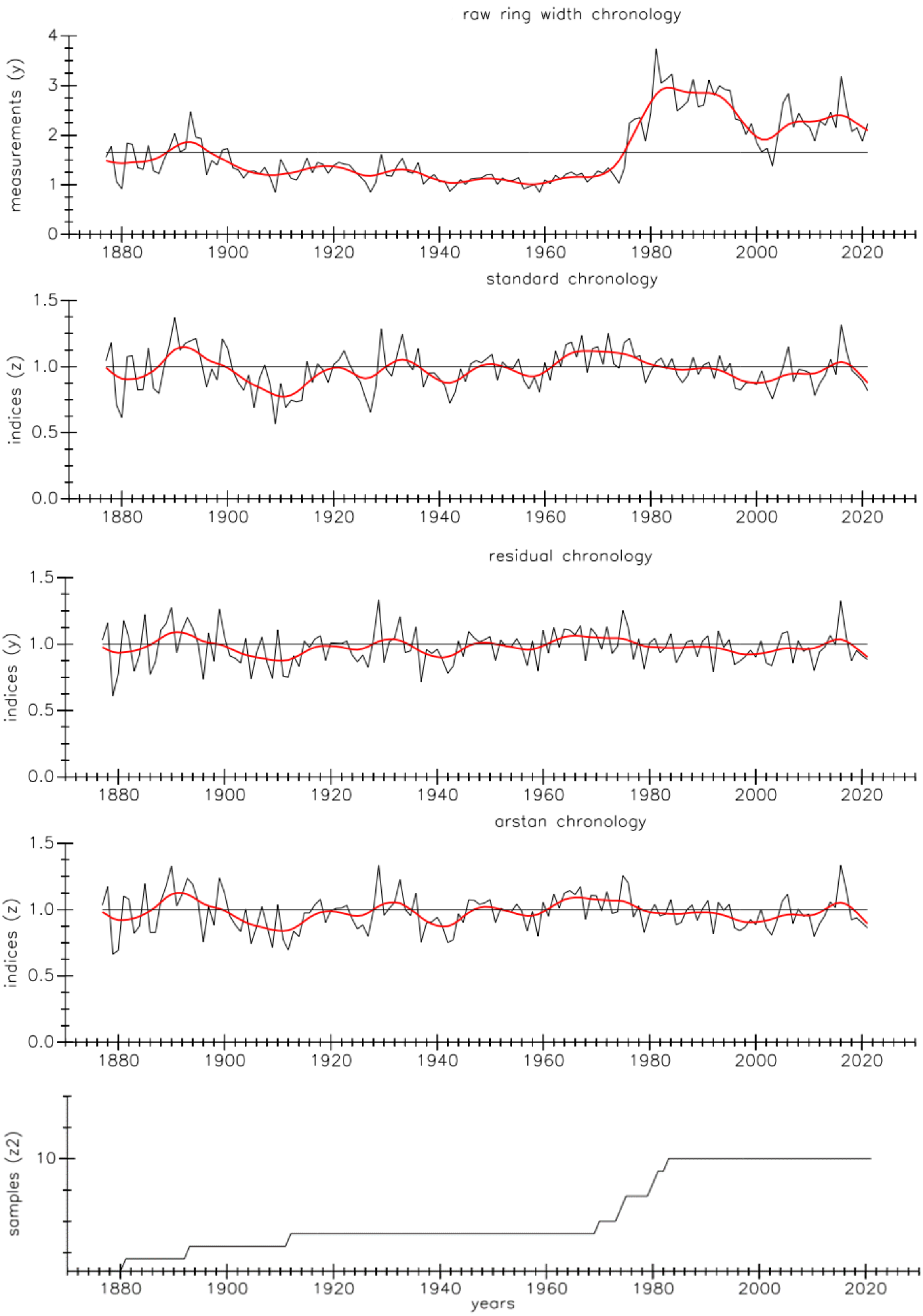


Figure 4. Chronologies (raw, standard, residual and arstan) and sample depth of *C. deodara* from Ayubia National Park, Pakistan

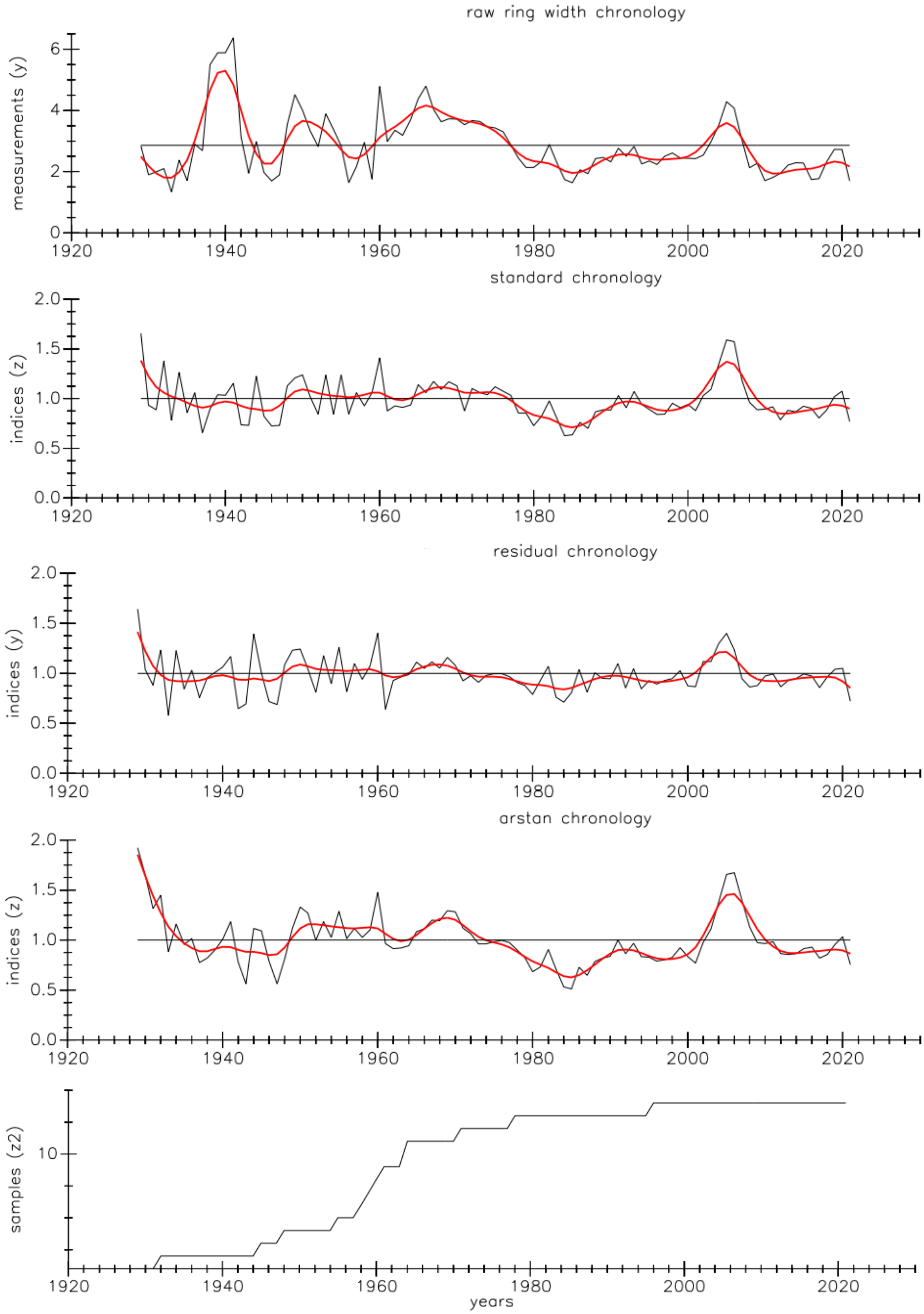


Figure 5. Chronologies (raw, standard, residual and arstan) and sample depth of *P. wallichiana* from Ayubia National Park, Pakistan

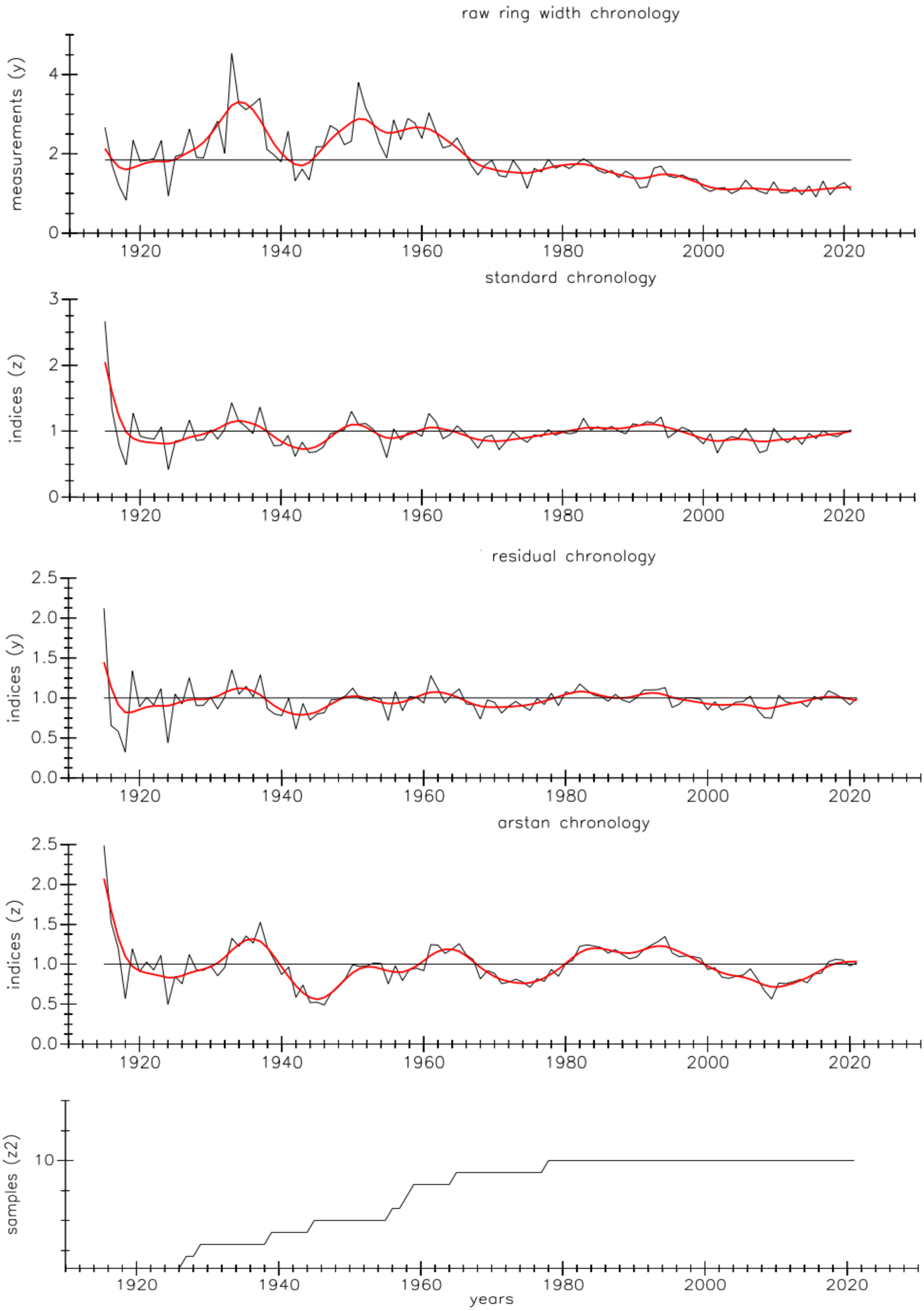


Figure 6. Chronologies (raw, standard, residual and arstan) and sample depth of *T. baccata* from Ayubia National Park, Pakistan

Ring width variations

All the species showed tremendous variations in ring-to-ring growth. Among the species, the lowest average mean ring width was recorded in tree-ring cores of *A. pindrow* (1.46 mm). The maximum value of average mean ring width of 2.99 mm was observed among *P. wallichiana* tree-ring cores. The widest tree-ring proliferation was 13.89 mm in *P. wallichiana* (Figure 7). The comparative mean ring widths are shown in Figure 8, depicting a greater number of narrow rings in *A. pindrow* and *T. baccata* while in *C. deodara* and *P. wallichiana*, wide rings are more abundant.

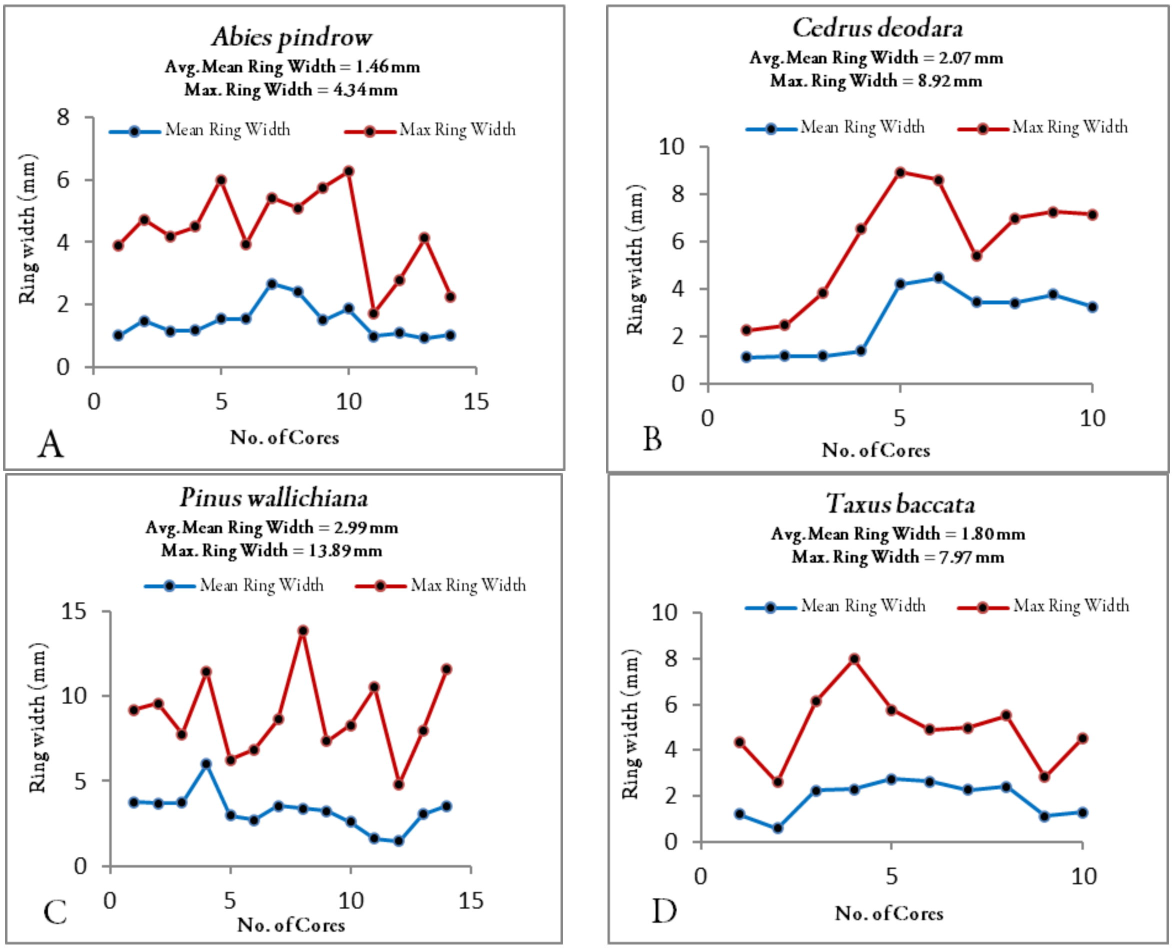


Figure 7. A-D: Ring width variations of species from the study site

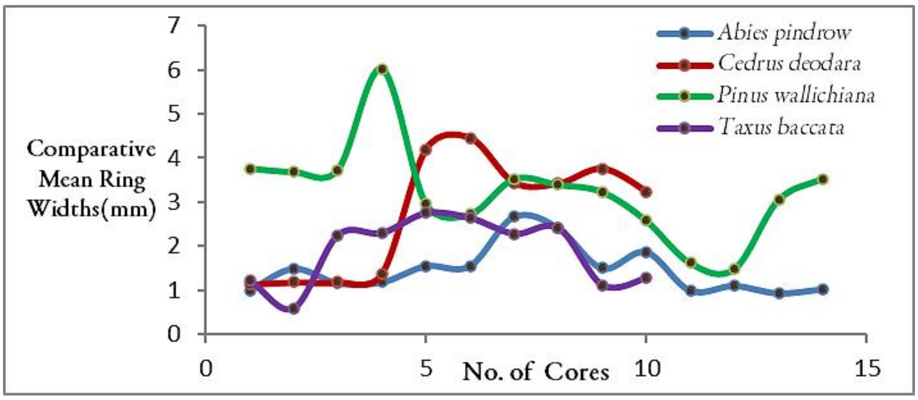


Figure 8. Comparative mean ring width analysis of 4 conifer species

Discussion

Conifer species are widely distributed among different geographical regions; mainly depend upon the resources available at particular sites. The species of moist temperate region are affected by various physical and biological factors of their regional climate, especially temperature and precipitation (Shaheen *et al.*, 2015). Among the selected species *P. wallichiana* showed the maximum tree ring growth rate of 0.05 cm per year as found by Siddiqui *et al.* (2013) in assessing the dendrochronological potential from moist temperate zone of Pakistan. A great variation was observed in the growth rate of the conifer species from same site and it is variable from site to site and from species to species (Ahmed *et al.*, 2009). Analysis of growth rate and DBH showed maximum value by *C. deodara* of 0.5942 and minimum by *T. baccata* of 0.0301. Thapa *et al.* (2014) developed 422 years long tree ring width chronology from Nepal Himalaya. Khan *et al.* (2020) found the age and growth rates of pine species from Murree, Pakistan. They performed correlation analysis between age and growth rate and DBH and growth rate. Xiong *et al.* (2000) studied the tree ring chronologies of conifers and hardwood species from three Gorges Reservoir regions of China. They assessed the dendrochronological potential of these species by studying their ring width measurements, ring characteristics, quality of cross dating by COFECHA and chronology development by ARSTAN.

With the help of COFECHA the quality of cross dating was checked and statistic values are given in Table 3. Among the selected conifer species *P. wallichiana* showed maximum mean ring width of 2.99 and minimum by *A. pindrow* of 1.40. Maximum mean sensitivity was observed in *T. baccata* of 0.328 and minimum by *A. pindrow* of 0.265. From minimum to maximum all the values of mean sensitivity are closer to 0.2 or are above 0.2 which according to Speer (2010) indicated that these tree species have good potential for past reconstructions. Auto-correlation values of these conifers ranges between 0.562 to 0.712 and it is according to Wahab (2011) the values of autocorrelations for conifer species ranges from 0.3 to 0.8.

Tree-ring measurements were standardized by the computer program ARSTAN and different versions of chronologies were produced for all the species of the study area. These chronologies included raw chronology, standard chronology, residual chronology and ARSTAN chronology. Tree ring chronologies of the species are given in the Figures 3, 4, 5, 6 and statistical values are given in the Table 4. Tree-ring chronologies showed distinct narrow, normal and wide years of tree-ring growth which were clear indications of the variable past climatic conditions (Ahmed and Zafar, 2014).

Among the cores of 4 species located at Ayubia National Park which comes under moist temperate ecoregion, *A. pindrow* showed greater sensitivity to climate change after Khan *et al.* (2020). *P. wallichiana* was found to be more adapted to the regional environmental conditions as depicted by excessive wide rings as shown in Figure 8. *C. deodara* and *T. baccata* showed variable patterns of tree-ring growth. The alternative and variant patterns among different cores of tree species specify the environmental extremes of the area after Muhammad *et al.* (2021).

Conclusions

It is concluded that these chronologies will be helpful for past climate investigation. Moreover, the chronology of the Ayubia National Park enclosed climatic signals and will be more helpful for the past climatic reconstructions as well as to explore more applied aspects through tree-ring studies like flood history, precipitation, volcanic eruptions, temperature fluctuations, droughts, snowfall variability and other seismological records of the forest region. It is also suggested that, to increase the sample size of this species, large sized trees should be acquired. According to Fritts (1976), to extend the chronologies older trees should be targeted for obtaining wood samples. The growth rate variations as observed from the different versions of the chronologies concluded that conifer species of the Ayubia National Park possess valuable potential for dendrochronological analysis.

Authors' Contributions

Conceptualization: SM, ZK; execution of investigation; MT, KR, HN, AA; drafting-original draft: MT, HN, AA; review, advice and supervision: SM, UFA, ZK.

All authors read and approved the final manuscript.

Ethical approval (for researches involving animals or humans)

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Conflict of Interests

The authors declare that there are no conflicts of interest related to this article.

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