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DENDROCHRONOLOGICAL INVESTIGATIONS REVEAL DECLINING GROWTH RATE OF *PINUS ROXBURGHII* SARG. POPULATIONS FROM 1840 TO 2017 IN KASHMIR HIMALAYAS

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Abstract

Pinus roxburghii Sarg. is a keystone gymnosperm tree of Western Himalayan subtropical forests of Kashmir region. It is a good choice for dendrochronological investigations as its core samples have potential to reflect changes in climatic pattern its growth rings. The present dendrochronological study was aimed to investigate the trends in growth as well as structural attributes of *P. roxburghii*. A cross dated tree-ring chronology for 177 years period was developed from 1840 to 2017. The average growth rate of *P. roxburghii* was calculated as 0.89 ± 0.02 year/cm. Tree Ring Width index revealed that *P. roxburghii* growth rate decreased from 1840-1880 AD whereas the growth rate significantly increased during the period 1890-1920 followed by a gradual decline afterwards till 2017. A total of 101 years were marked with slow growth whereas higher growth was found in 75 years. The decline in growth rate is synchronized with the disturbance stimuli and socioeconomic transformations in the study area during the last century. The average DBH was recorded to be 87.87 cm, ranging from a minimum of 70.5 cm to a maximum of 108.5 cm whereas the average core length was recorded as 21.2 cm. The average age of *P. roxburghii* trees was calculated to be 123.06 years with the oldest tree specimen of 245 years. The decline in the Pinus growth rate appears to be synchronized with climate change induced increasing temperatures during the last century. It is recommended that the tree rings chronologies should be constructed for further keystone taxa to reconstruct past climatic history in this region.

Key words: Chronology; Climate Change; Growth Rate; Kashmir Himalayas; Tree rings.

Introduction

Dendrochronology is a multidisciplinary science based upon the study of tree rings formed during the annual growth (Leavitt & Bannister, 2009). Annual growth ring formation is a linear function influenced by series of events of environmental factors (Brienen & Zuidema, 2005). Dendrochronology has many applications that help to understand the tree growth, historic climate patterns, insect outbreaks, and wildfire patterns (Grissino-Mayer, 2003). The tree writes its own history, telling us not only the number of years, but also the information about the prevailing environmental conditions (Fonti *et al*., 2007). The Tree species produce annual growth rings due to vascular cambium activity in response to the climatic factors (Lisi *et al*., 2008). The cells formed during spring season under favorable climatic conditions sow a rapid radial growth with a bigger lumen and thinner walls whereas those formed during winter or unfavorable conditions have the thicker walls and smaller lumen (Eckstein, 2004). Tree rings study provides significant information about the impact of climatic and seasonal variation on the growth pattern and wood anatomy based on density and fluctuations in intra-annual rings (Krepkowski *et al*., 2012). Dendrochronology can also be used to assess the biomass productivity from an ecosystem (Dhyani *et al*., 2022; Kipfmueller & Salzer, 2010; Zywiec *et al*., 2017).

Conifer species show great potential for dendrochronological studies because of higher sensitivity to the environmental factors and long age (Bokhari *et al*., 2013). *Pinus roxburghii* Sarg. is a keystone tree species making the bulk of subtropical forests in lower elevation zone of western Himalayas (Shah *et al*., 2015). Although the higher elevational temperate forests comprise of several conifer species including *Abies pindrow, Pinus wallichiana, Picea smithiana,* and *Cedrus deodara*; *Pinus roxburghii* is the only conifer that is found in lower elevational subtropical forests (Ahmed, 2014). Previously, the age of some conifer trees had been calculated in Pakistan by using method of simple counting, but the results of those studies showed over estimation of age (Mbow *et al*., 2013).

Accurate data is not available for longer durations for any specific Himalayan forested landscape due to very few sparsely installed meteorological stations in the vast Himalayan Mountains. Hence enough dendrochronological studies have not been done in the western Himalayas forest types (Srivastava *et al*., 2001; Singh *et al*., 2005). Tree-ring chronologies in the Lesser Himalayan subtropics are vital because these areas are relatively underrepresented by proxy data (Tiwari *et al*., 2020). This information is significant for understanding the ecological dynamics and to infer broad-scale climate phenomena of the past as well as predict the future climate change scenarios (D'Arrigo *et al*., 2006; Brienen *et al*., 2009).

Current research is the pioneer study on the dendrochronological investigations of *P. roxburghii* in the subtropical zone of Kashmir region. No previous studies have investigated this species with high population level representation. It is hypothesized that climate change and anthropogenic disturbances may have negatively affected the growth rate of *Pinus roxburghii* in the region which can be assessed through dendrochronological analysis. This study specifically aims to analyze the growth rate of *P. roxburghii* populations by studying the annual growth ring patterns and to investigate the relationship of dendrochronological parameters with age, DBH and growth rate.

Materials and Methods

Study area: The Study area lies in the western Himalayan state of Azad Jammu and Kashmir, Pakistan located between longitude 73° to 75° East and latitude 33° to 36° north comprising an area of 13,297 Km^2 (GOAJK, 2015; Fig. 1). The investigated study sites were located in *P. roxburghii* pure stands in the 600-1400 m elevational range in the subtropical monsoon zone with an average annual rainfall of 1000 -1300 mm. Summers are hot with an average temperature of 25°C to 32°C whereas winters are mild with 04°Cto 07°C (Pak-Met, 2016). A total of 16 different sites with different geographical location, elevation and slope angle were taken in Muzaffarabad, Bagh, Poonch, Mirpur and Kotli districts with the aim to cover maximum geographical spread and diverse microclimatic variations across the species range. The geographical characteristics of the sites including altitude, longitude and latitude, slope and aspect were recorded by using the GPS device i.e., Garmin Corp. 2000.

Data collection and analysis: *P. roxburghii* wood core samples were taken from alive trees taken at diameter at breast height using Swedish increment borer following standard protocols (Stokes, 1996). Samples were taken opposite to the radii in all the trees with maximum DBH values for cross match ring pattern as it showed variation in the same species according to Cleavland (1986). Extracted cores samples were labeled, processed, and polished for dendrochronological analysis in the tree ring laboratory by using binocular long arm microscope (Ahmed, 2014).

Skeleton plot technique was used for visual cross dating following Stokes (1996). Narrow and wide rings with respect to year were drawn on skeleton graph. The cores showing narrow rings in the same year were considered as pointer years. Wood sample reliability was calculated by using the following formula Ogden (1980).

Reliability: Actual length of core/ tree radius x 100

COFECHA program was used to develop master chronology with statistically compared segments of 50 years from each measured core against the master core (Eckstein *et al*., 2004). The ARSTRAN program was used to develop series of tree ring measurements by maximizing the common signals and reducing the noise produced in the chronologies (Therrel *et al*., 2007). Generalized Linear correlation analysis was performed to analyze the relationship between structural and dendrochronological attributes using PAST software package Version 4.04.

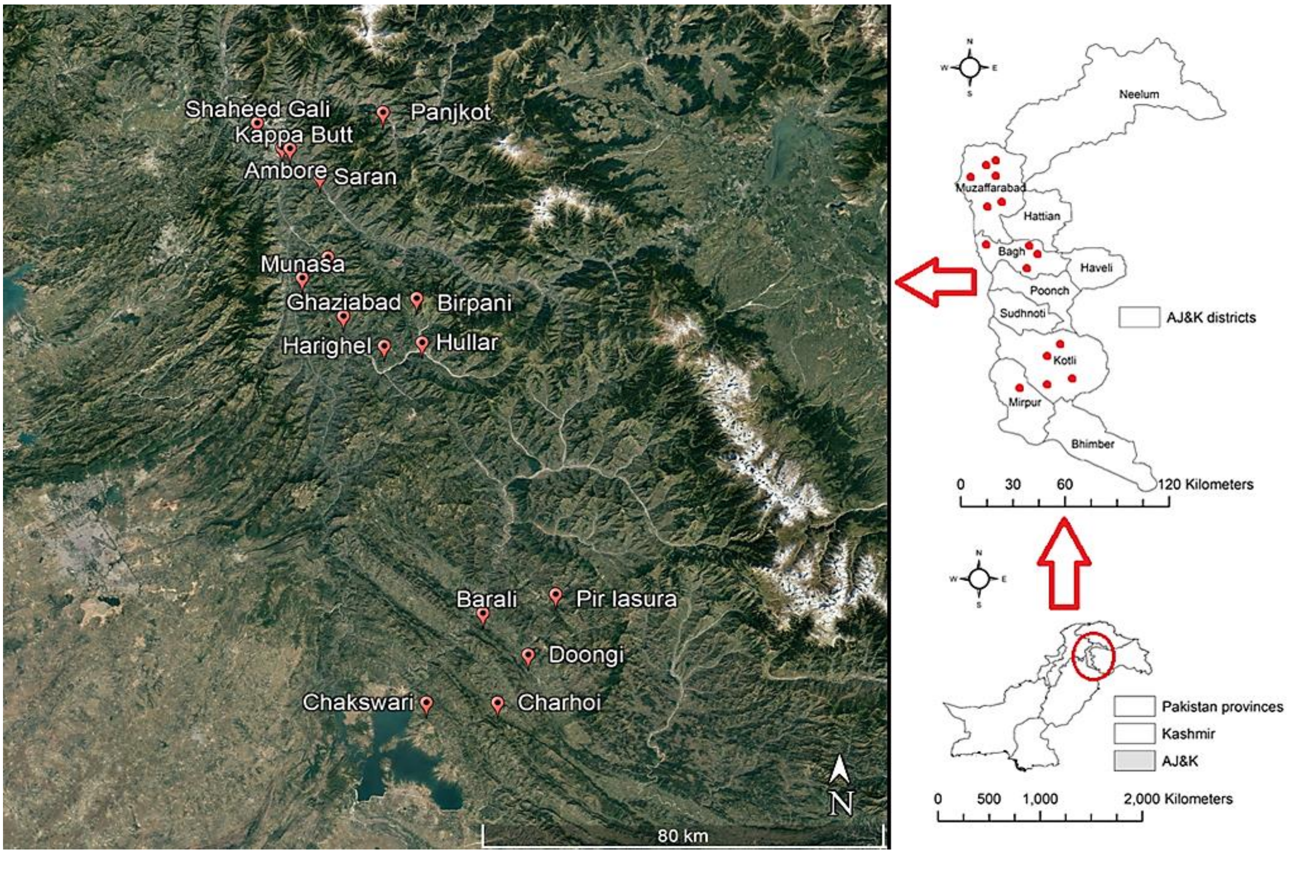

Fig. 1. Map of the study are and location of the *Pinus roxburghii* sampling sites.

Table 1. Structural and Dendrochronological attributes of *Pinus roxburghii* populations in Azad Jammu and Kashmir.

S.No.	Site name	Elevation Range (m)		Aspect	Cores No.	DBH Range			Total age range			Growth rate					
												Year/cm			cm/Year		
		Min	Max			Min	Max	Mean	Min	Max	Mean	Min	Max	Mean ±SE	Min	Max	Mean ±SE
1.	Kappa Butt	809	882	E	11	55	152	**103.5**	59	188	123.5	0.64	1.46	1.11 ± 0.07	0.69	1.64	0.96 ± 0.04
2.	Ammbor	819	1107	E	14	58	150	**104**	43	159	101	0.67	1.69	1.11 ± 0.03	0.59	1.5	0.99 ± 0.02
3.	Saran	2240	2457	S-W	13	50	143	96.5	46	245	**145.5**	0.68	1.94	1.30 ± 0.02	0.51	1.48	0.84 ± 0.07
4.	Danna	1603	1815	E	15	48	107	77.5	73	185	129	1.21	1.66	**1.76 ± 0.05**	0.38	0.83	0.59 ± 0.02
5.	Panjkot	1280	1425	E-N	15	70	125	97.5	142	196	**169**	1.35	2.49	**1.85 ± 0.04**	0.41	0.74	0.55 ± 0.02
6.	Shaheed Galli	1398	1510	S	16	61	105	83	47	183	115	0.52	2.7	1.39 ± 0.07	0.37	1.92	0.86 ± 0.08
7.	Ghazi Abad	1219	1266	E-S	10	62	155	**108.5**	61	228	**244.5**	0.87	2.17	1.52 ± 0.8	0.46	1.14	0.69 ± 0.06
8.	Harigehel	944	1097	S-W	10	50	110	80	44	190	117	0.67	2.53	1.2 ± 0.07	0.39	1.48	0.95 ± 0.08
9.	Munasa	1283	1316	N-S	10	55	90	72.5	28	143	85.5	0.5	1.63	1.05 ± 0.07	0.61	1.96	**1.12 ± 0.10**
10.	Hullor	1355	1494	N-W	10	62	130	96	51	176	113.5	0.65	1.83	1.22 ± 0.10	0.54	1.53	0.9 ± 0.10
11.	Birpani	1796	1968	E	8	58	118	88	49	184	116.5	0.61	1.55	0.92 ± 0.10	0.64	1.63	**1.11 ± 0.10**
12.	Barali	723	964	E	10	54	120	87	35	176	105.5	0.59	1.91	1.33 ± 0.09	0.52	1.58	0.88 ± 0.11
13.	Doongi	831	950	E	10	56	100	78	39	162	100.5	0.59	1.68	1.18 ± 0.06	0.59	1.68	0.97 ± 0.10
14.	Pirlasoura	1246	1308	S-E	10	48	110	79	32	207	119.5	0.64	2.43	1.39 ± 0.07	0.41	1.56	0.82 ± 0.06
15.	Charohi	640	794	S-E	10	54	87	70.5	40	109	74.5	0.65	1.29	0.92 ± 0.02	0.77	1.53	**1.13 ± 0.04**
16.	Chakswari	488	716	S-W	8	65	104	84.5	43	175	109	0.65	2.1	1.52 ± 0.09	0.47	1.53	0.73 ± 0.07
	Average				11.2	56.6	119.1	87.88	52.0	181.6	123.1	0.72	1.94		0.52	1.48	

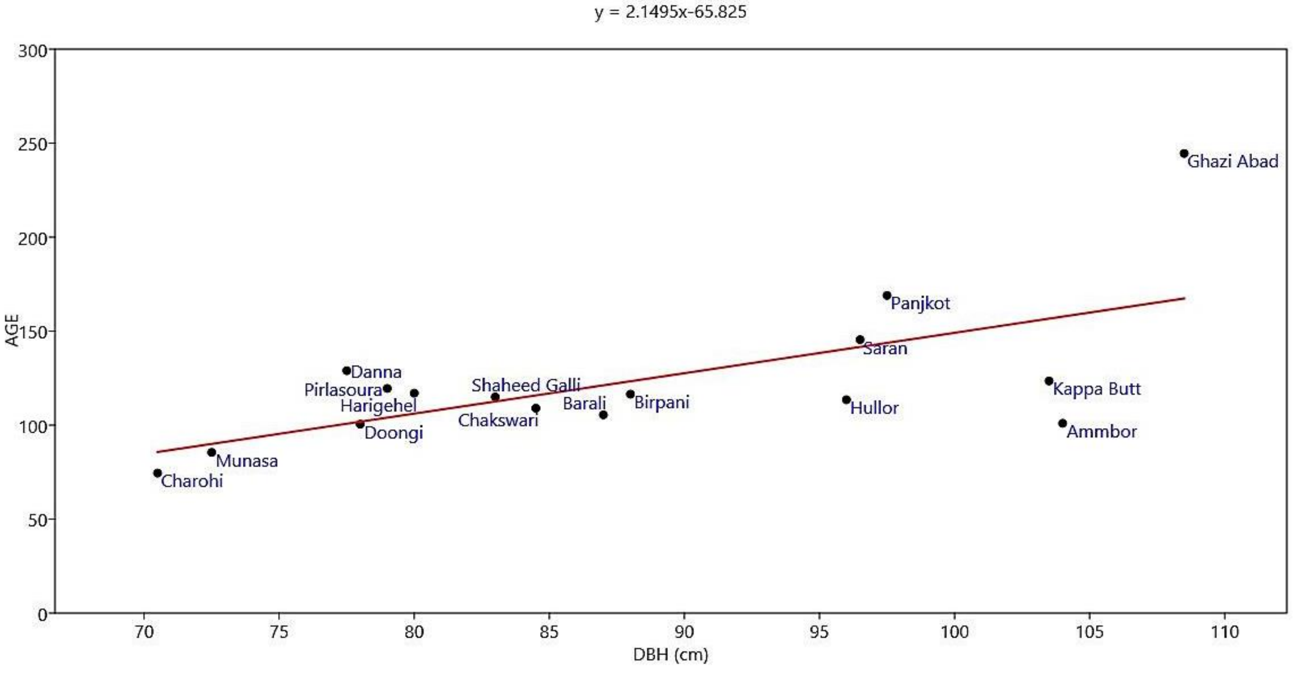

Fig. 2. Generalized linear model of age vs DBH.

Results

Growth rate and age: A total of 210 cores samples were extracted from 180 trees sampled at 16 study sites for dendrochronological investigations. A cross dated tree-ring chronology for 177 years period was developed from 1840 to 2017 AD. The average growth rate of *P. roxburghii* was calculated to be 0.88 cm/year among all sites. The lowest growth rate of was calculated as 0.37 cm/year recorded at Shaheed Galli whereas the highest was recorded as 1.96 cm/year was recorded from Munasa site.

The average age of *P. roxburghii* populations was calculated to be 123.06 years. Ghaziabad Site was recorded to be characterized with highest average age of 244.5 years whereas Charhoi site showed a minimum average age of 74.5 years. The individual tree specimen with the highest age of 245 years was recorded from Saran (Table 1).

Tree ring index: The Tree-ring index demonstrated that the growth rate of this species showed sharp fluctuations during 1840-1880 AD whereas a significant increase was observed from AD 1890-1920. Then again, the growth rate slightly decreased up to 2017 (Fig. 2). The number of total core samples used for cross dated chronology series were 22 having a master series age of 177 years with a total number of rings as 3047. The average value of rings in cross dated cores was 138.5 years with a maximum number of cross dated rings as177 years whereas the minimum rings were recorded as 133 years. The value of the correlation for the chronology series was found to be as 0.107 with an average mean sensitivity of 0.383. Narrow rings were recorded in a total of 83 years whereas very Narrow rings recorded in a total of 18 years. Wide rings were recorded in a total of 70 years while Very Wide rings were in a total of 5 years. PC scores obtained from TRW chronology showed that PC 1 score were comparatively higher reflecting that first detrending and negative exponential curve was best fit for reconstruction model (Figs. 3-6).

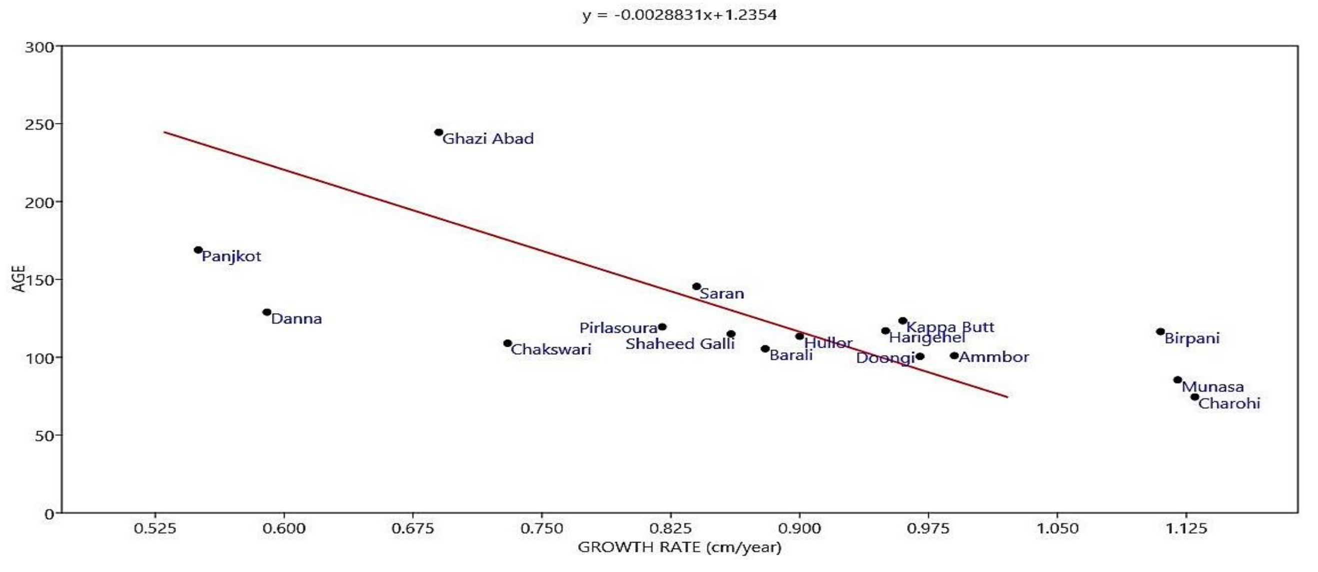

Fig. 3. Generalized linear model of age vs. growth rate.

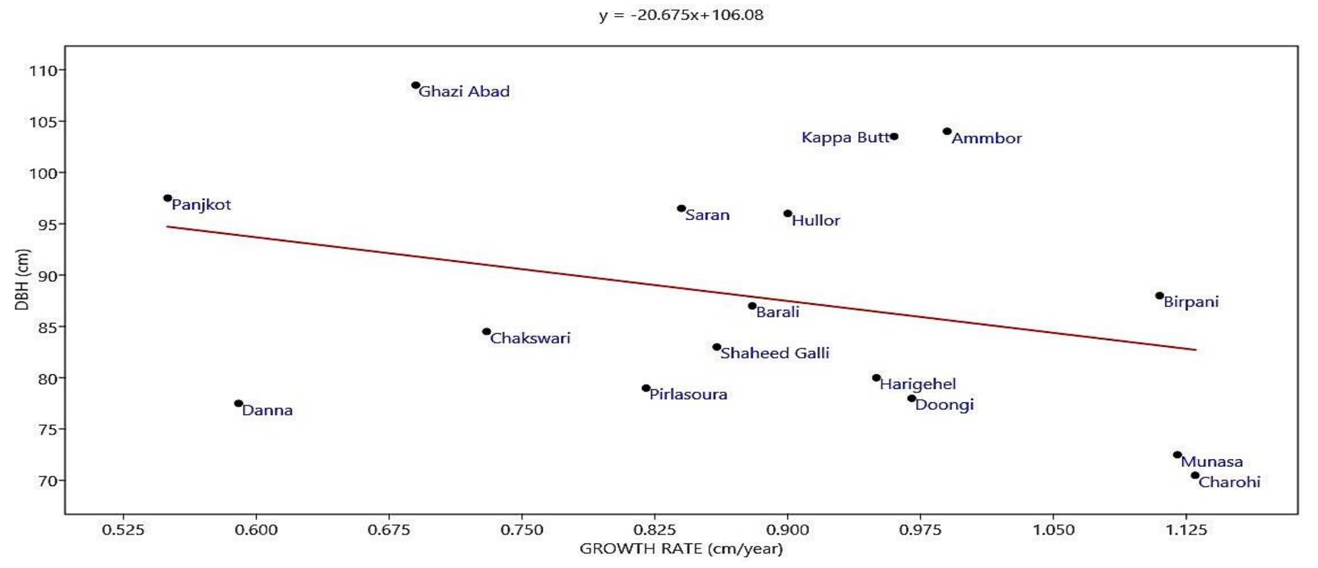

Fig. 4. Generalized linear model of growth rate vs age.

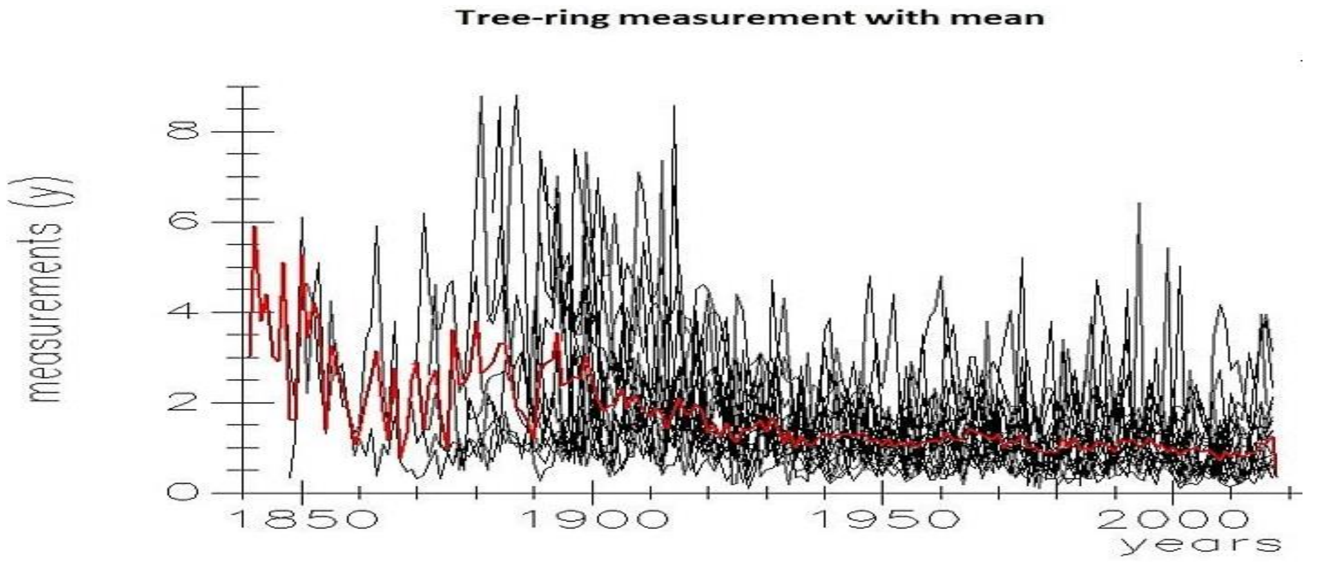

Fig. 5. Tree ring width index values for *Pinus roxburghii* from 1860 to 2017.

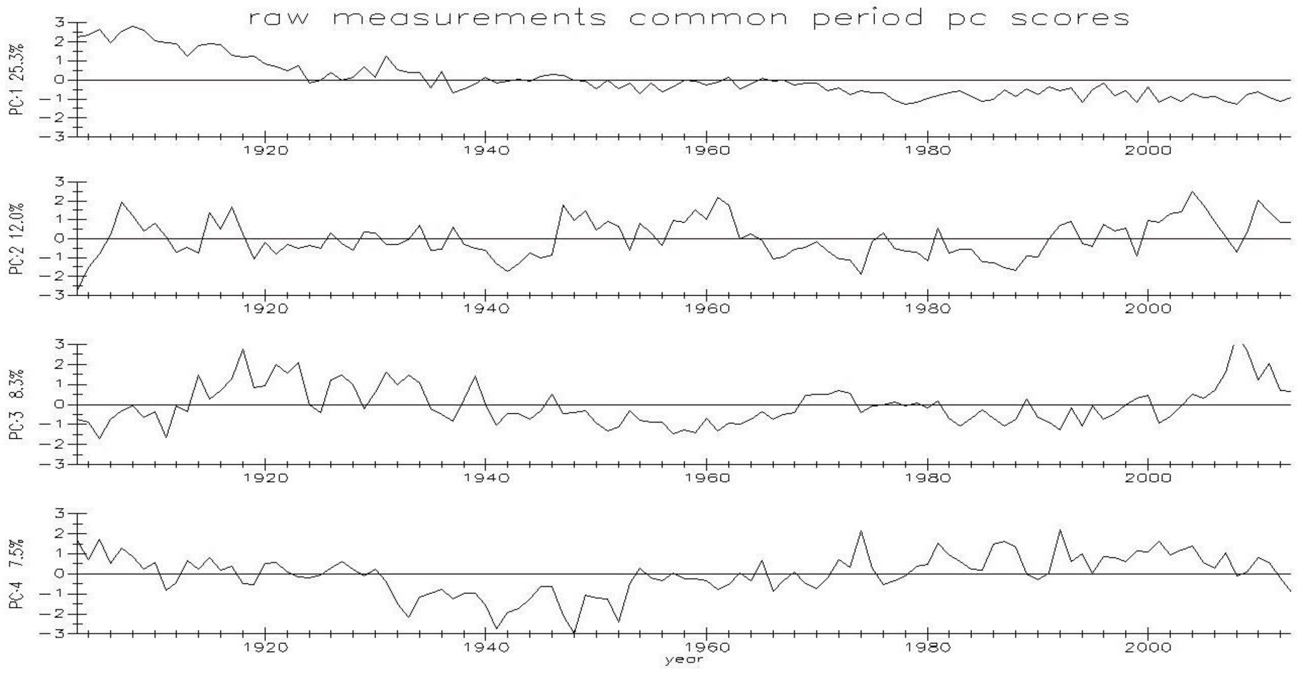

Fig. 6. Principal component scores for the tree ring chronology.

Table 2. Pearson's Linear Correlation values of the investigated dendrochronological and structural attributes.

Site code	DBH Vs age		DBH Vs Growth rate		Age Vs Growth rate	
	r	P value	r	P value	r	P value
Kappa Butt	0.823	***p*<0.001**	-1.8	Ns	-1.37	Ns
Ammbor	0.47	Ns	-1.01	Ns	0.54	Ns
Saran	0.775	***p*<0.001**	-0.301	Ns	0.583	*p*<0.05
Danna	0.665	*p*<0.01	-1.73	***p*<0.001**	-0.94	***p*<0.001**
Panjkot	-1.61	*p*<0.01	-1.82	***p*<0.001**	-0.56	*p*<0.01
Shaheed Galli	-0.379	Ns	-0.78	***p*<0.001**	0.888	***p*<0.001**
Ghazi Abad	1.5571	*p*<0.01	-0.788	***p*<0.001**	0.36	Ns
Harigehel	0.574	*p*<0.05	-0.216	Ns	0.882	***p*<0.001**
Munasa	0.44	Ns	-0.37	Ns	0.877	***p*<0.001**
Hullor	0.70	*p*<0.01	-0.12	Ns	0.76	*p*<0.01
Birpani	0.755	***p*<0.001**	0.654	*p*<0.05	0.177	Ns
Barali	0.544	*p*<0.05	-0.56	*p*<0.05	0.82	***p*<0.001**
Doongi	0.64	*p*<0.05	0.24	Ns	0.81	***p*<0.001**
Pirlasoura	0.82	***p*<0.001**	-0.39	Ns	0.34	Ns
Charohi	0.60	*p*<0.05	-0.46	Ns	0.72	*p*<0.01
Chakswari	0.54	Ns	-0.56	Ns	0.821	*p*<0.01

DBH and core length values: The *P. roxburghii* populations in the study area showed an average tree DBH of 87.87 cm. The minimum individual DBH was recorded as 48 cm recorded from Danna site at an altitude of 1603 m whereas a maximum of 155 cm at Ghaziabad site. The average core length among all the samples was calculated to be 21.2 cm with a minimum of 11 cm whereas the maximum core length for an individual specimen was 28.5 cm.

Pearson's correlation test: The Pearson's Correlation test showed a strong linear correlation between DBH and age in 12 out of 16 study sites having a significance value of $p<0.001$. The correlation between age and growth rate followed the same trend having significant ($p<0.001$) values at 10 sites. On the contrary a non-significant correlation was revealed between DBH and growth rate where only 6 out of 16 sites showed a significance value (Table 2).

Discussion

Pinus roxburghii is one of the most important gymnosperm species and a vital component of the sub-tropical forest stands of Western Himalayan foothills in Azad Jammu and Kashmir. *P. roxburghii* exhibits clear annual growth rings which can be analyzed and interpreted to reveal past climatic history because of experiencing a long climatic continuum (Speer *et al.*, 2017). Dendrochronological records of *Pinus* species for age and growth estimation in the Himalayan forests reveal that the growth rate significantly correlates with the tree age and Diameter (Ahmed & Naqvi, 2005).

Statistical analysis revealed highly significant relationship (p<0.001) between DBH and age whereas a non-significant relationship was observed in DBH and growth rate (Table 2). The core samples having similar DBH values showed different number of rings and variable ages. This may be attributed to microclimatic differences between the sampled cores from different geographical locations leading to a marked difference in growth rate and ring formation (Wyckoff *et al*., 2005; Ahmed & Sarangzai, 1991). An astonishing finding was observed at Hullar Site where 2 core samples with the same DBH of 100 cm showed contrasting results for age as 65 and 162 years, respectively. On close observation of the sampled sites, it was found that the samples were taken from 2 different quadrates lying at different aspects which was an important geographic variable having significant impacts on tree growth (Hussain, 2013). The tree sample with higher age and growth rate was located at South facing aspect with greater sun light insolation resulting in better growth whereas the lower aged sample was located at north facing slope with limited solar insolation subsequently resulting in retarded growth. The similar effect of aspect on growth rate was recorded in dendrochronological studies on *Cedrus deodara* species in northern Pakistan (Ahmed, 2009).

The association between age and DBH is not linear even in identical species due to widespread variations in structural and geographical characters (Khan *et al*., 2008). Although *P. roxburghii* shows slower growth compared to other gymnosperm species due to environmental stresses; but due to its inherent strength and best fitted niches, attains higher age (Larson, 2011; Singh *et al*., 2014). In our study, the oldest age of an individual sample was recorded *as 245* years with a diameter of 126 cm and reliability of 45.2% at North-Western aspect. This value is considerably higher than that of *Picea smithiana* with an age of 196 years with 90 cm DBH (Wahab *et al*., 2011) as well as *Pinus wallichiana* with an average age of 130 years having 153 cm DNH value (Siddiqui *et al*., 2013).

Altitude is another important environmental variable having direct correlation with the growth rate pattern (Iqbal *et al*., 2017). *Pinus roxburghii* exhibits maximum growth rate at moderate altitudes in 900-1500 m range (Ahmed *et al*., 2010); and the same had been observed at most of our sampling sites. However, deviations from this general trend were observed at specific sites like Charhoi at 640 m along with Munasa and Birpani sites on 1283 and 1796 m respectively showing Highest growth rates as 1.1-1.3 cm/year despite of significant variations in the altitude. The lowest mean growth rate as 0.55 cm/years was also recorded from Danna Kachili and Panjkot sites at 1200-1600 m altitude against the general trend. Ahmed & Sarangzai (1991, 1992) reported similar growth trend in *Pinus wallichiana* from moist temperate forest of Murree, Pakistan. A significant variation was observed in the pattern of individual years with narrow and the wide growth rings in the current study. Our observations are in harmony with the studies of Bhokari *et al*., (2013).

Anthropogenic disturbances are considered to have severe deteriorating impacts on tree growth patterns (Dale *et al*., 2001; Touchan *et al*., 2005). *P. roxburghii* forests in the Himalayan foothills are adversely affected by anthropogenic activities along with the climate induced stresses (Verma *et al*., 2018). During samples collection, it was observed that *P. roxburghii* stands in the study area were subjected to multiple disturbances including fire, logging, and soil degradation. The disturbed sites including Danna, Panjkot, Ghaziabad and Chakswari showed lowest growth rates (<0.7 cm/year) along with lower values of DBH and Age attributed to the intense disturbance.

The tree ring chronology developed for 177 years ranging from 1840-2017 demonstrated a decreasing growth rate during 1840-1880 AD whereas the growth rate significantly increased from 1840-1920 AD followed by a gradual decline afterwards from 1920 till 2017 (Fig. 2). This decreasing trend is synchronized with massive socioeconomic transformations in the area in the last century involving huge population rise, roads and infrastructure development and the subsequent forest degradation in the whole region (Shaheen *et al*., 2011).

Conclusion

Dendrochronological investigations of *P. roxburghii* ranging from 1840-2017 AD revealed significant variations in the tree growth rate pattern and a correlation with socioeconomic transformations in the area. This data provides a baseline information about this key stone gymnosperm species forming the main bulk of western Himalayan subtropical forests in Kashmir Region revealing past growth history characterized with a declining trend. The decline in the Pinus growth rate appears to be synchronized with climate change induced increasing temperatures during the last century. It is recommended that the Tree rings chronologies should be constructed for further gymnosperms to investigate the growth patterns and reconstruct past climatic history of specific species in this region.

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