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Tree-ring studies from Kashmir Valley: Present status and future perspectives

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ABSTRACT

In Kashmir Valley, conifer taxa such as *Abies pindrow, Cedrus deodara, Picea smithiana* and *Pinus willichiana* are found promising for tree-ring studies. In the present analysis, we assessed the tree-ring studies carried out so far in the Kashmir Valley and its vicinity in relation to various parameters of climate study and discussed the prospect and challenges. The various parameters like ring-width, earlywood, latewood, maximum latewood density, minimum earlywood density and isotope were used to reconstruct climatic variables such as temperature, precipitation and Palmer Drought Severity Index (PDSI) beyond the existing instrumental data. It has been observed that *Abies pindrow* is extensively used taxa for tree-ring analysis from this region. The tree-ring chronology lengths vary from 117 to 373 years. However, adjoining areas of Kashmir Valley recorded 400 to 500 years long ring-width chronology. The dendroclimatic potential of the taxa from the region was established earlier, but the numbers of sample studied based on the various taxa are very limited. Moreover, the datasets studied earlier have been used multiple times in various studies without updating with new samples. Thus, it was observed that the region has a dearth of analysis based on maximum sample depth and old trees. So far, only conifer taxa are considered for tree-ring analysis even though broad-leaved taxa like *Betula utilis* growing in tree line of the valley produce annual ring. The maximum spatial coverage of tree-ring network shall provide a more effective understanding of the spatial and temporal variation in past climate.

Key-words: Kashmir Valley, Tree-ring, Conifers, Climate reconstruction.

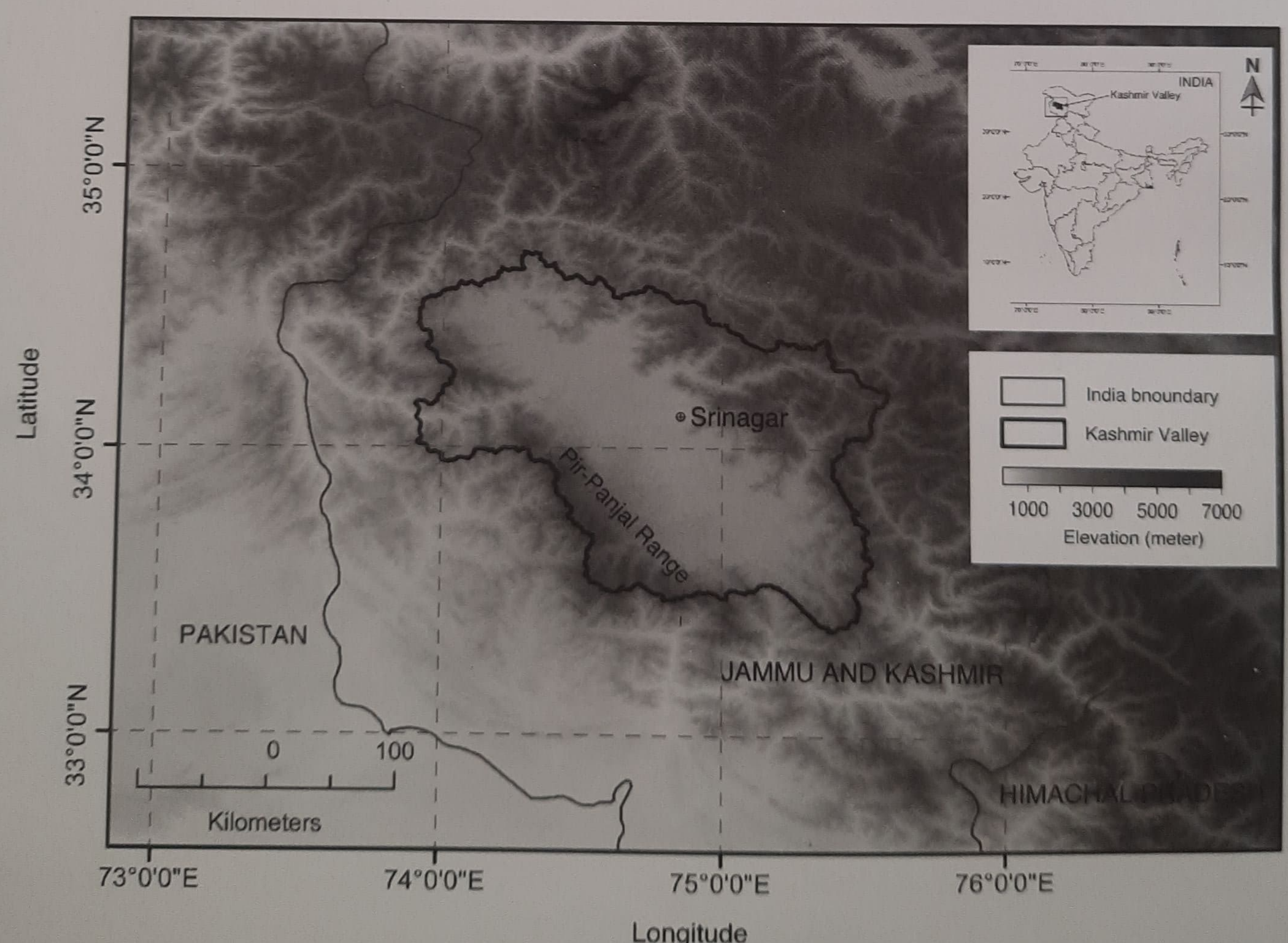
INTRODUCTION

Kashmir valley is surrounded by high mountain chains on all sides with varied climatic zones. Except Srinagar, the instrumental climate records in Kashmir Valley are mostly available from early seventies of the twentieth century. For better understanding of the climate scenario of the region and future climate projection, longer climate data is required. There have been a few proxy based records from the region which decipher the past climate variations during the Late Quaternary. These proxy records are: pollen (Singh 1964, Vishnu-Mittre & Sharma 1966, Sharma & Vishnu-Mittre 1969, Gupta & Sharma 1989, Gupta et al. 1984, 1985, Sharma et al. 1985, Dodia 1988, Gupta 1991), megaflora remains (Puri 1947, 1948, Vishnu-Mittre & Robert 1973) and Isotope (Krishnamurthy et al. 1982). However, these records have less information of the climatic variations that occurred during the recent millennium. Such millennium records are significant to understand the variability in the climate system in higher resolution time scales and for future climate modeling. The study of recent two-millennium climate variability using various proxies have become one of the latest time frame for the regional working groups in the globe (PAGES 2K working groups: *www.pages-igbp.org/ini/wg/2k-network/regional-2k-groups*) and mostly preferred for climate modelling.

The higher resolution proxies in annual scale, such as tree-rings would provide climate reconstructions beyond the existing instrumental data. High altitude conifer taxa such as *Abies, Cedrus, Juniper, Picea, Pinus* spp etc. are excellent recorder of climatic variability in annual, centennial and millennium scale. These taxa are variably distributed over the Himalaya from Karakoram to Bhutan and Arunachal Pradesh Himalaya (Troup 1921, Dallimore & Jackson 1923, Sahni 1990). A number of tree-ring studies of these species have provided long term climate records (temperature and precipitation) from the entire Himalaya region (Bhattacharyya & Shah 2009). There are also other long term records such as river discharge variations, fire history, glacial fluctuations, earthquake and drought events from tree-ring studies of Himalayan conifer and broad leaved taxa (Bhattacharyya & Shah 2009, Brown et al. 2011, Shah et al. 2013, Shah et al. 2014a, 2014b). Ironically, there are not many such detailed tree-ring records from the Kashmir Valley. In the present review, we attempt to understand the tree-ring based studies on various conifer taxa in the Kashmir Valley and its nearest periphery. We reviewed the present status of the available tree-ring records, tree-ring parameters analyzed, spatio-temporal extent of climate reconstruction, and various other environmental phenomena recorded in tree-ring studies from Kashmir Valley.

Geographical Setting

The Kashmir Valley (also known as Vale of Kashmir) is a longitudinal depression in the great northwestern complex of the Himalayan ranges (Text figure 1) and has a strong genetic relationship with Himalayan complex constituting important relief feature of geographic significance. The physiographic features of the northwestern Himalayan complex lays down the very premise for the identification of the Kashmir Valley as situated within the frame of the mountain systems which define clearly the watersheds and basins (Raza et al. 1978). The valley lies between 33°20' to 34°54' N Latitudes and 73°55' to 75°35' E Longitudes, covering an area of 15,948 km^2 (Dar & Khuroo 2013) and is surrounded by an unbroken ring of mountains which gives it a character of an enclosed vale. The valley is surrounded by Karakoram in the north, Pir Panjal



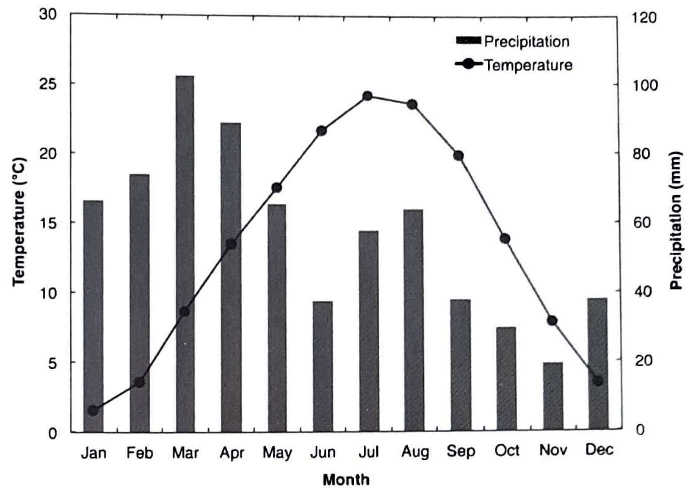
Text Figure 1. Map showing the location of Kashmir valley where the tree-ring studies have been reviewed.

Range in the south and west, Zanskar Range in the east and Siwalik hills towards south. The bowl shaped basin is fault-bounded basin or extensional rift basin and has a tendency to sink with respect to the general rise of the Himalaya (Agarwal & Agarwal 2005).

Climate and Vegetation

The Kashmir Valley has distinct climatic peculiarities due to its location at a high altitude in the northwestern corner of the subcontinent, and is enclosed within high mountain ranges. The southern arm of the mountains, Pir Panjal ranges act as an effective barrier to the summer monsoon – the chief bearer of moisture in the subcontinent. Thus, the summer rainfall of the valley clearly reflects this shadow-effect that stops the moisture from entering the valley. The monsoon winds during the summer cause rain in the outer plain and their outer Hills. Moreover, these winds can cross the Pir Panjal to enter the valley only when they are very strong. The Great Himalaya creates little obstructive influence on the influx of the westerly troughs that enter the valley from the west and the northwest during winter and cause snowfall and rain. The precipitation in winter, in the form of snow helps to maintain moisture supply as during summer rainfall is less than evapo-transpiration in the valley.

The climatic variability of the valley has been studied and analyzed time to time on the basis of existing instrumental climate data. Kumar & Jain (2010) analyzed seasonal and annual rainfall and rainy days at five stations of Kashmir Valley to study the rainfall trends. The analyzed data were for different time periods. However, the study concluded that the trends on rainfall patterns in the valley have impact on economy of the valley. Hence there is a need to implement the issue of climate change in the planning and management of water resources. Ashraf (2013) studied spatio-temporal variation of precipitation in Kashmir Valley using six meteorological stations viz. Pahalgam, Kokernag, Kupwara, Gulmarg, Srinagar and Qazikund for the period of AD 1975-2009. The trend analysis shows that, except for Qazikund, the total amount of rainfall had decreased significantly. The precipitation of these stations are also found to have positive correlations with North Atlantic Oscillation (NAO) for winter (Ashraf 2013). The trend analysis carried out for six stations viz. Gulmarg, Pahalgam, Qazikund, Kokernag, Kupwara and Srinagar of the Kashmir Valley over the period 1980-2010 depicts that warming trend for spring and winter is more significant as compare to other seasons (Zaz & Romshoo 2013). The observed mean annual minimum and maximum temperature from 1980 to 2010 at two meteorological stations, Pahalgam and Gulmarg show a significant rising trend over the years. The projected temperature for these meteorological stations also shows an increasing trend under all the climate scenarios (Rashid et al. 2015). It has been observed that the minimum temperature in the region is rising faster than the maximum temperature (Rashid et al. 2015).



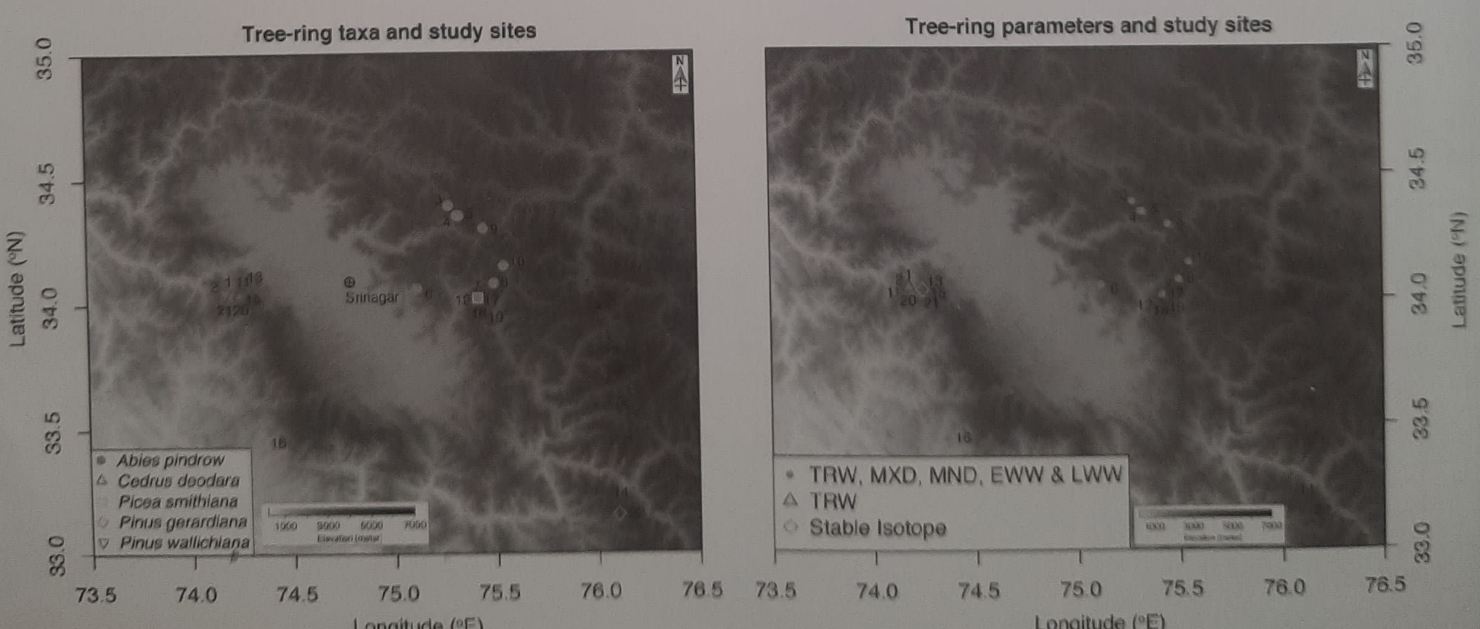
Text Figure 2. Climograph for Srinagar meteorological station over the period AD 1893-2014. Data were obtained from Global Historical Climate Network (GHCN).

The meteorological station, Srinagar has both instrumental records of temperature and precipitation since AD 1893. The records from this station have been analyzed and discussed earlier in various climate studies (Pant et al. 1999, Archer & Fowler 2004, Fowler & Archer, 2006, Bhutiyani et al. 2007, 2010, Jeelani 2012). We analyzed the updated temperature and precipitation data of Srinagar (source, GHCN). The monthly average temperature and monthly total precipitation records at Srinagar over the period AD 1893-2014 are shown in Text figure 2. The hottest months are July and August with average temperature of 24°C. There is distinct winter season of December-February with coldest month as January (1.5°C). The total annual precipitation is 679.80 mm and the month of March-April receives highest rainfall (191.2 mm) and October-November is amongst the driest months (Text figure 2). These varied climatic conditions have marked influence on the flora and fauna of the valley.

The flora of the Kashmir Valley has been explored since early nineteenth century by several workers (Singh et al. 2002 and references therein). The type of forest and associated taxa in the Kashmir Valley have been updated and enumerated in various studies (Singh 1929, Muthoo & Wali 1963, Enayatullah & Tikku 1964, 1965, Muthoo 1965, Singh & Kachroo 1994, Ara et al. 1995, Dar & Christensen 1999, Dar et al. 2001, Dar & Dar 2006a, 2006b, Dar & Khuroo 2013). There are certain factors which influence the form, size and type of characteristics vegetation found in varied assemblages and association patterns in different parts of the Kashmir Valley both horizontally and vertically. These factors are lithology, slope, altitude, soil and climatic variables such as temperature, moisture, intensity and duration of sunshine and atmospheric humidity (Raza et al. 1978). The generalized vegetation belts based on the altitudinal zoning of vegetation (Dar & Khuroo 2013) are the temperate forests (1600-2700 m) comprising usually the conifers, such as Blue Pine (*Pinus wallichiana*), Himalayan Deodar (*Cedrus deodara*), Silver Fir (*Abies pindrow*), Spruce (*Picea smithiana*) and the Himalayan Yew (*Taxus wallichiana*), with some associated broad-leaved trees and shrubs. The other forest type is the Sub Alpine forest (2700-3500 m), which is dominated by Silver Fir in the lower reaches, while natural stands of Birch occur above 3200 m. In this belt, Birch usually forms the timberline, while beyond the tree line, alpine scrub vegetation is found. The alpine scrub comprises mainly the species of *Juniperus*, *Rhododendron*, *Salix*, *Lonicera* and *Cotoneaster*. Dar & Dar (2006b) provided the taxonomic appraisal of conifers of Kashmir Himalaya and concluded conifers constitutes an important floristic component of the evergreen forests. We further describe the taxa considered for tree-ring based analysis in different parts of the valley and inferences drawn from these studies in terms of spatio-temporal variations in different environmental factors.

STATUS OF TREE-RING PROXY RECORDS IN THE REGION

In this section we are assessing the tree-ring studies carried out on various taxa so far in the Kashmir Valley and its vicinity (Text figure 3) using various tree-ring parameters (Text figure 3). We have also discussed the tree-ring studies carried out in each tree taxa with number of trees and cores (Text figure 4) and the tree age (Text figure 4) obtained for climate analysis and reconstructions. The details of the tree-ring studies



Text Figure 3. Map showing the location of tree-ring sites for various taxa (left panel) and various tree-ring parameters with study sites (right panel) in Kashmir Valley. The details of the numbers adjacent to each location are provided in Table 1.

carried out earlier in the Kashmir Valley and its vicinity is provided in Table 1.

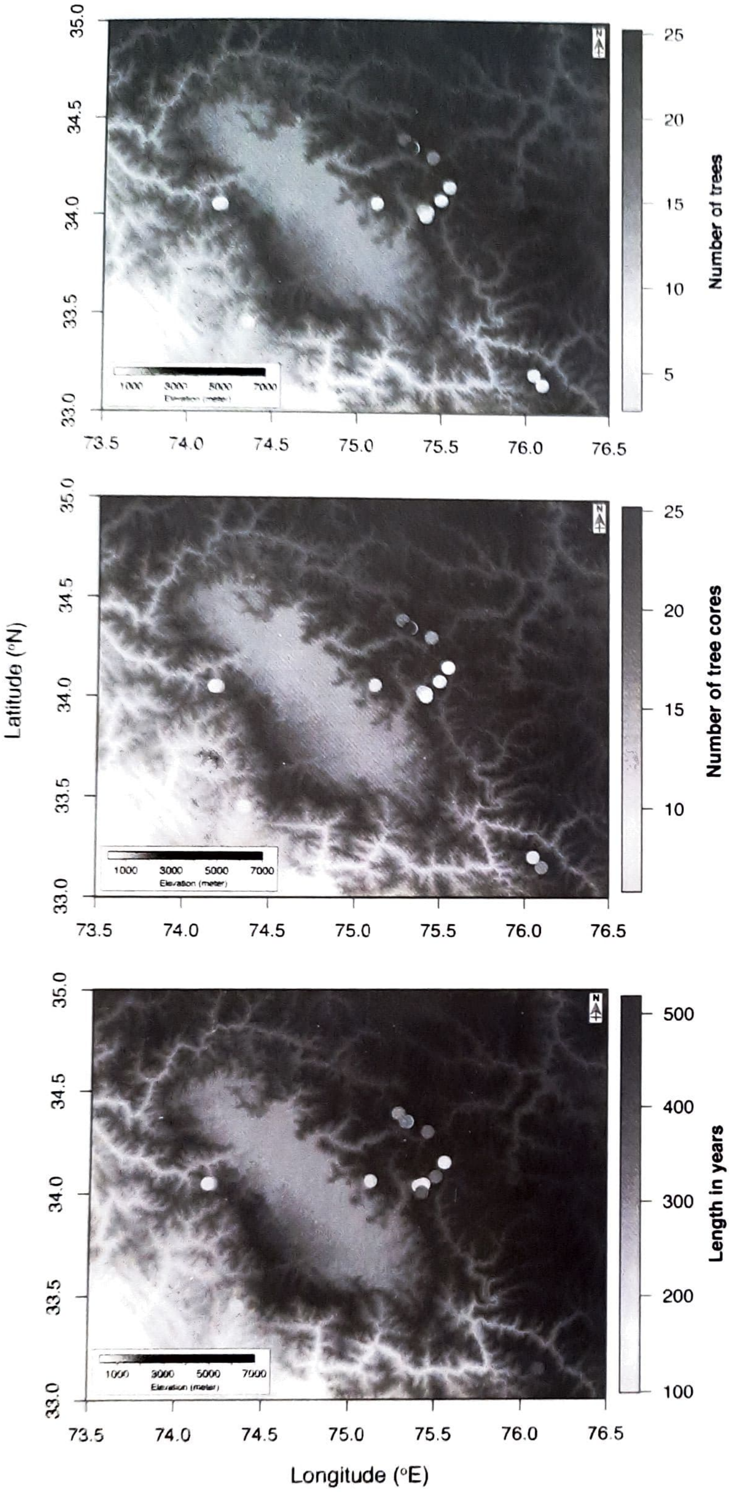
Tree-ring studies on *Abies pindrow*:

The tree-ring based studies in the Kashmir valley has been dominated by analysis of *A. pindrow* distributed in various parts of the valley. The exploratory collection of tree-ring sample of *A. pindrow* was carried out during 1980 and 1982 from ten localities distributed in the Lidder Valley, Sindh Valley and the Pir Panjal Range (Hughes & Davies 1987). The chronologies *A. pindrow* were prepared for tree-ring parameters such

Table 1. The tree-ring studies carried out in Kashmir Valley and reviewed in this paper

SN	TAXA	Site name	LAT	LONG	NT	NC	Time span	CL	Tree-ring Parameters	References
1	*Abies pindrow*	Gulmarg	35.05	74.18	15	18	1620-1980	361	TRW, MXD, MND, EWW, LWW	Hughes and Davies 1987, Hughes 1992, Hughes 2001, Ram and Borgaonkar 2013
2	*Abies pindrow*	Khillanmarg	35.05	74.20	9	13	1668-1980	313	TRW, MXD, MND, EWW, LWW	Hughes and Davies 1987, Hughes 1992, Hughes 2001, Ram and Borgaonkar 2013
3	*Abies pindrow*	West of Sonmarg	34.39	75.28	17	17	1682-1982	301	TRW, MXD, MND, EWW, LWW	Hughes and Davies 1987, Hughes 1992, Hughes 2001
4	*Abies pindrow*	Sonmarg	34.35	75.33	6	6	1764-1980	217	TRW, MXD, MND, EWW, LWW	Hughes and Davies, 1987, Hughes 1992, Hughes 2001
5	*Abies pindrow*	Thijwas	34.35	75.32	25	25	1655-1982	328	TRW, MXD, MND, EWW, LWW	Hughes and Davies 1987, Hughes 1992, Hughes 2001
6	*Abies pindrow*	Sarbal	34.30	75.45	16	16	1644-1982	339	TRW, MXD, MND, EWW, LWW	Hughes and Davies 1987, Hughes 1992, Hughes 2001
7	*Abies pindrow*	Pahlgam	34.02	75.42	9	9	1656-1980	325	TRW, MXD, MND, EWW, LWW	Hughes and Davies 1987, Hughes 1992
8	*Abies pindrow*	Chandanwadi	34.15	75.55	9	9	1777-1982	206	TRW, MXD, MND, EWW, LWW	Hughes and Davies 1987, Hughes 1992, Hughes 2001, Ram and Borgaonkar 2014
9	*Abies pindrow*	Arau Valley	34.06	75.12	7	7	1880-1982	103	TRW, MXD, MND, EWW, LWW	Hughes and Davies 1987, Hughes 2001
10	*Abies pindrow*	Sesnag	35.05	75.50	6	6	1636-1982	347	TRW, MXD, MND, EWW, LWW	Hughes and Davies 1987, Hughes 2001
11	*Abies pindrow*	Gulmarg	34.05	74.18	3	8	1805-1983	179	TRW	Bhattacharya et al. 1988
12	*Abies pindrow*	Pahalgum	34.02	75.42	8	8	1612-1982	371	TRW	Borgaonkar et al. 1994, Ram 2012, Ram and Borgaonkar 2013
13	*Abies pindrow*	Gulmarg	34.04	74.25	2	4	1903-1932	30	Stable Isotope (δD, $\delta^{13}C$, $\delta^{18}O$)	Ramesh et al. 1985, Ramesh et al. 1986
14	*Cedrus deodara*	Sashu	33.20	76.05	3	10	1469-1983	515	TRW	Bhattacharya et al. 1988
15	*Cedrus deodara*	Gulmarg	34.04	74.25	1	1	1923-1932	10	Stable Isotope (δD, $\delta^{13}C$, $\delta^{18}O$)	Ramesh et al. 1985
16	*Picea smithiana*	Yusmarg	33.45	74.36	7	8	1780-1980	201	TRW, MXD, MND, EWW, LWW	Hughes and Davies 1987
17	*Picea smithiana*	Bhaisaran	34.02	75.42	7	11	1826-1982	157	TRW, MXD, MND, EWW, LWW	Hughes and Davies 1987
18	*Picea smithiana*	Pahalgum	34.42	75.42	3	7	1819-1983	165	TRW	Bhattacharya et al. 1988
19	*Picea smithiana*	Pahalgum	34.02	75.42	13	13	1775-1982	208	TRW	Borgaonkar et al. 1994, Ram 2012, Ram and Borgaonkar 2013
20	*Pinus wallichiana*	Gulmarg	35.05	74.18	4	8	1767-1983	217	TRW	Bhattacharya et al. 1988
21	*Pinus wallichiana*	Gulmarg	34.04	74.25	1	1	1923-1932	10	Stable Isotope (δD, $\delta^{13}C$, $\delta^{18}O$)	Ramesh et al. 1985
22	*Pinus gerardiana*	Sashu	33.15	76.10	5	16	1583-1983	401	TRW	Bhattacharya et al. 1988

SN = Serial number and also represented in Text figs. 2 and 3; LAT = site latitude in °N; LONG = site longitude in °E; NT = number of trees used to develop chronology; NC = number of cores used to develop chronology; CL = chronology length in years; TRW = total ring width mean; MXD = maximum density mean; MND = minimum density mean; EWW = earlywood width mean; LWW = latewood width mean



Text Figure 4. Map showing number of trees and tree cores used to develop tree-ring chronologies and tree-ring chronology lengths (total years) from various sites at Kashmir Valley.

as Maximum Latewood Density (MXD), Minimum Earlywood Density (MND), Earlywood width (EWW), Latewood width (LWW) and Total Ring width (TRW) from these localities for all the sites and analyzed for dendrochronological inferences. The shortest and longest chronology is ranging between 103 years (AD 1880-1982) and 361 years (AD 1620-1980) (Table 1). The eight longest chronologies of *A. pindrow* for each tree-ring parameter were analyzed for variance and exhibited strong regional coherence. These tree-ring parameters explain variance percentages of about 61% (MXD), 29% (EWW), 47% (LWW) and 45% (TRW) for a common period of ninety years (AD 1891-1980) showing similar regional growth pattern. Among the parameters studied, MND shows little common pattern for any combination of site and species in terms of proportion of variance. The serial correlations are recorded higher in case of MXD, which exhibited great persistence as compared with this variable in other genera studied elsewhere in the globe (Hughes & Davies 1987). The cross dating and t-values were calculated between series of *A. pindrow* chronologies from various sites, for parameters namely MXD, EWW, LWW and TRW. The t-values for the MXD series are markedly higher than other parameters specifically at sites from Pir Panjal Range and Sindh Valley. The correlation coefficients of the mean of the longest eight *A. pindrow* MXD series chronologies, with mean April to September air temperatures recorded in Srinagar are significantly high ($r = 0.53$) for the common period AD 1893-1980. Hughes and Davis (1987) attributed the strong similarity in regional pattern of MXD of *A. pindrow* existing at distant sites such as in Gulmarg in the Pir Panjal Range and Sonemarg in Sindh Valley to environmental factors such as growth season temperatures. A preliminary attempt was made to reconstruct temperature from 1890 to 1980 using densitometry and ring-width data of this species. The study carried out on tree-ring analysis of *A. pindrow* by Hughes & Davies (1987) described the feasibility of extracting information on past environments, especially climate, from the annual rings of subalpine conifers. There is a very considerable promise for the successful application of dendroclimatological techniques in Kashmir and neighboring areas. Bhattacharyya et al. (1988) prepared ring width chronology of *A. pindrow* from Gulmarg, spanning AD 1805-1983 based on eight core samples from three trees. The chronology statistics was calculated and compared with tree-ring series from various other taxa collected in Kashmir Valley.

The *A. pindrow* tree-ring series studied by Hughes & Davies (1987) were re-analyzed for further dendroclimatic reconstructions (Hughes 1992). They inferred that the spring temperature, late summer temperature and growth season rainfall on the basis of eight ring width and seven density series of *A. pindrow.* The reconstruction was from AD 1894 to 1780 using instrumental data recorded by the Srinagar meteorological station. The mean regional maximum latewood density series further estimated the spring temperature for the period of ninety years between AD 1690 and 1779. The reconstructed temperature series recorded cold spring years (1864, 1823, 1817, 1769, 1755 and 1694) and cold late summer years (1823, 1800, 1795 and 1794). Similarly, the reconstructed precipitation captured years of wet growing seasons in the years 1891, 1864 and 1817. The study encourages the tree-ring studies from the Kashmir Valley, along with other localities of the Indian Himalaya.

Another study of this species along with *P. smithiana* from Pahalgam, Anantanag District, based on eight core samples collected from eight trees, chronology for the period AD 1612-1982 was prepared (Borgaonkar et al. 1994). The response function analysis showed significant relationship of climatic parameters and tree-ring width. The temperature records of summer months (May-July) depicted a negative response whereas the winter and spring months (October-March, except January and February) show a positive response. The precipitation records (May-September) were relatively more significant and show consistent positive relationship with tree-growth, except for the month of June. The reconstruction was made for the summer precipitation (May–September) up to AD 1775 using instrumental records from the Srinagar metrological station. It is noted here, that the wet and dry years recorded in the reconstruction by Borgaonkar et al. (1994) were different from the ones noted earlier by Hughes (1992). This was attributed to the minor difference in the calibration techniques and seasons selected. Borgaonkar et al. (1994) also emphasized on the future use of multiple–species chronology network over a wider area for climate reconstructions in Kashmir, which could extend up to 400-500 years.

With the advancement of techniques and statistical methodologies, the previous dataset of ring-width and density variable of *A. pindrow* was assessed by preparing regional chronology (Hughes 2001). The multi-decadal climate variability was retained by applying conservative techniques of removal of the effects of age/size and trend on the data set. A summer temperature reconstruction was compiled in a split manner where the earlier reconstruction of April through September was improved by excluding July month. Hughes (2001) emphasized that the new summer temperature reconstruction is an improvement over the previous reconstruction(s) because the new summer temperature reconstruction has a decadal to multi-decadal variability distributed throughout the reconstruction and is longer compared to the previous reconstruction(s). Also, the early years of the site chronologies had an issue of inadequate replication, which was solved by calculating mean regional chronologies using the best samples. In this study, climate signals were assessed for MXD, LWW, and TRW using response function methods (Fritts 1971, 1976) for each site chronologies. The MXD and LWW exhibited response to precipitation but, more strongly responded to temperatures at the beginning (April-May) and end (August-September) of the growing season. However, the MXD and LWW series had a minor negative response for July temperatures resulting in the elimination of July temperatures in the reconstruction. The models with the July temperature performed poorly in terms calibration and verifications statistics leading to a split reconstruction. The temperature reconstruction using regional chronologies was extended up to AD 1660 based on the MXD and TRW of ten longest core sample of *A. pindrow.*

The tree-ring data set of Borgaonkar et al. (1994) was re–analyzed for tree growth-climate relationship and summer Palmer Drought Severity Index (PDSI) reconstruction (Ram 2012). Bootstrap correlation analysis was carried between gridded climate data set from CRU (Mitchell & Jones 2005), PDSI (Dai et al. 2004) and ring width index chronology of *A. pindrow* during AD 1902-1982. The current year May, July and September rainfall had positive and significant correlation with the chronology of *A. pindrow*. The temperature of the current year for the month of May had significantly negative correlation. Based on the response shown by monthly climate variable, seasonal averaged climate was also used to derive correlation with ring-width index. Ram (2012) has already explained that the correlation based on seasonal average climate with ring-width index might be more representative of moisture conditions during the growing season than a single month. The PDSI values for months from previous year October to current year October (except April and August) revealed significant positive correlations with tree-ring index. The study by Ram (2012) depicted that the tree growth of *A. pindrow* is very sensitive to moisture availability of the region due to higher correlation with PDSI as compared to rainfall and temperature. A combination of the ring width series of *A. pindrow* with *P. smithiana* in total of 21 core samples (8 cores of *A. pindrow* and 13 cores of *P. smithiana*) was used for the study. This was done due to the high correlation (0.41) for the period of 1781-1982 among the chronologies of these two taxa. The summer season's PDSI of the region has been reconstructed from AD 1820 to1981 using the combined chronology of *A. pindrow* and *P. smithiana*. The reconstruction of PDSI was truncated at AD 1819 on the basis of EPS threshold level (>0.85) (Wigley et al. 1984) achieved by the chronology. The reconstruction of PDSI captured that the low soil moisture occurred during 1830-1834, 1848-1849, 1859-1876, 1887-1901, 1933-1953, 1964-1973, and high soil moisture during 1836-1839, 1857,1927--1930, 1979-1981 and comparable with PDSI calculated for nearest grid points of sampling site in MADA (Cook et al. 2010). Among these the longest period of low soil moisture occurred during AD 1859-1876.

Ram and Borgaonkar (2013) studied the growth response of *A. pindrow* with gridded climate data of precipitation, temperature, vapour pressure and PDSI. In this study, a regional chronology was prepared using tree-ring data of *A. pindrow* analyzed in Borgaonkar et al. (1994), two sites tree-ring data of *A. pindrow* of Hughes and Davies (1987) along with *P. smithiana* from Pahalgam (Borgaonkar et al. 1994) and Juniper tree-ring data from Karakoram (Esper et al. 2007). The principal component retained for the common period of all tree-ring data of multi-species has been used to establish growth response with various climatic parameters. The study shows that the first principal component among the site chronologies is strongly correlated with PDSI during summer season (May-July). The increased temperature of the region had significant adverse effect on tree growth. The growing season's moisture availability is found more conducive in developing the annual tree-ring width compared to rainfall during the season. In addition, the increasing temperature and vapour pressure during November and December of the previous year might play an important role for early snow melt over the region, which maintains enough soil moisture favoring trees growth during subsequent growing season of the trees as well as in physiological processes. However, they also discussed the disturbance caused by biotic and abiotic factors that influenced tree growth over the region, which makes it difficult to understand the interactions between tree growth and climate.

Ram and Borgaonkar (2014) re-analyzed the tree-ring parameters of *A. pindrow* data set from one site (Chandanwari) studied by Hughes and Davies (1987) for various climatic responses (mean, maximum and minimum temperatures, precipitation and PDSI). The analysis showed that TRW and ERW compared to LRW are strongly correlated with PDSI during summer season (March to October). The relationship weakened as temperature changed over the region, whereas Maximum Latewood Density (MXD) reveals significant negative association with PDSI during summer season. Moreover, monthly mean, maximum and minimum temperatures during August to September of the region indicate significant positive response with MXD.

Tree-ring studies on *Picea smithiana*:

The exploratory collection of tree-ring sample of *P. smithiana* was carried out during 1980 and 1982 from two localities: the Lidder Valley and the Pir Panjal Range (Hughes and Davies 1987). The tree-ring parameters such as MXD, MND, EWW, LWW and TRW were studied and their chronologies were prepared. The shortest and longest chronology is 157 years (AD 1826-1982) and 201 years (AD 1780-

1980) from the Lidder Valley and the Pir Panjal Range, respectively (Table 1). These two *P. smithiana* chronologies show strong affinities with *A. pindrow* tree-ring network analyzed in Hughes and Davies (1987) and maximum affinities have been recorded for MXD chronology. Another tree-ring width chronology of 165 years (AD 1819-1983) was prepared from Pahalgam, Lidder Valley by Bhattacharyya et al. (1988). This chronology was almost of same age compared to *P. smithiana* chronology, developed by Hughes and Davies (1987) from the Lidder Valley.

Borgaonkar et al. (1994) collected 13 core samples of *P. smithiana* from Pahalgam, Lidder Valley and prepared 208 years (AD 1775-1982) tree-ring chronology. This study is from the same locality where earlier collection were made by Hughes and Davies (1987) and Bhattacharyya et al. (1988). The study of Borgaonkar et al. (1994) shows that *P. smithiana* has significant negative response to summer (May-July) temperature and a significant positive response with summer (May-September) precipitation. Their study demonstrated that a multiple species chronology network would be very useful for reconstruction. Furthermore, summer (May-September) precipitation has been reconstructed by the authors by combining the tree-ring width chronology of *P. smithiana* with *A. pindrow*.

Ram (2012) re-analyzed ring width index chronology of *Picea smiathiana* studied by Borgaonkar et al. (1994). In this study, this species along with *A. pindrow* has been analyzed for tree-growth climate relationship and for the reconstruction of PDSI. The study revealed significant positive correlations with May and July rainfall and a significant positive correlations with June-October PDSI. For temperature, the chronology revealed significant negative correlations with mean, maximum and minimum temperature of May and positive with November of the previous year. The same site tree-ring chronology has been also utilized to develop regional chronology with other species and to analyze its growth response with climate data (Ram & Borgaonkar, 2013). A detailed inference on the studies involving *P. smiathiana* has been already discussed in the above section along with *A. pindrow*.

Tree-ring studies on *Cedrus deodara* and *Pinus gerardiana*:

Bhattacharyya et al. (1988) carried out reconnaissance dendrochronology of conifer species of northwest India. Their study shows the dendrochronological potentiality of *Cedrus deodara* and *Pinus gerardiana* growing under stress conditions at Sashu, near Kistwar. The studies on these taxa were based on a small number of trees (10 cores from 3 trees of *C. deodara* and 16 cores from 5 trees of *P. gerardiana*) but made reconnaissance survey for the development of old tree-ring chronology. The two tree-ring chronologies, 515 years (AD 1469-1983) chronology of *C. deodara* and 401 years (AD 1583-1983) chronology of *P. gerardiana* prepared from the above-mentioned stress site shows good cross-dating among all the cores of individual species and amongst *C. deodara* and *P. gerardiana*. The occurrence of missing rings is higher (2.05%) in *P. gerardiana* as compared to *C. deodara* (0.97%) and some of the cores of *P. gerardiana* were difficult to date due to the apparent absence of many rings. Based on the tree-ring chronology prepared from these two species, Bhattacharyya et al. (1988) concluded the possibility of development of long drought sensitive chronology from this region.

Tree-ring studies on *Pinus wallichiana*:

Bhattacharyya et al. (1988) prepared 217 years (AD 1767-1983) long tree-ring width chronology from Gulmarg, Kashmir Valley and discussed its chronology strengths based on various chronology statistics. Bhattacharyya et al. (1988) discussed close association of *P. wallichiana* tree-ring chronology with *A. pindrow* chronology and consequently prepared composite chronology based on the two taxa.

Tree-ring studies on *Juniperus* spp.:

The tree form of *Juniperus* spp. is usually absent in the Kashmir Valley. Alhtough, few patches of scrub of Juniper are reported from the high elevation areas such as Gulmarg forest, Sindh forest and Zojila Rocky Mountains (Dar and Dar 2006a). However, tree-ring analysis carried out on two discs of Juniper (*Juniperus macropoda*) from adjoining areas of the Kashmir

Himalaya i.e., Karakoram have the ring counts of 1200 and 479 respectively (Bilham et al. 1983). The authors have shown detection of incomplete rings in different radial sections from both the specimens and have suggested that the age of the trees might have been more than what is indicated by their ring counts.

Tree-ring studies using stable isotope:

Besides various ring-width parameters and density studies on *A. pindrow*, there are a few exploratory studies that reveal that stable isotopic ratio from tree-rings also have a good potential for palaeoclimate studies in the region. The isotopic analysis of the extracted tree-ring cellulose from *A. pindrow* growing in Gulmarg, Kashmir, revealed that δD is most sensitive to precipitation and mean maximum temperature, whereas $\delta^{13}C$ and $\delta^{18}O$ are sensitive to temperature and cloud amount and humidity respectively (Ramesh et al. 1985, 1986). In addition to *A. pindrow*, a preliminary experiment was also conducted on isotope analysis of tree-ring of *C. deodara* and *P. wallichiana* from the same locality to study the species effect on the coherence of the isotope signal in different species of the region (Ramesh et al. 1985).

DISCUSSION AND FUTURE PROSPECTS

Tree-ring based palaeoclimatic records from Kashmir Valley are mainly concentrated on temperature, precipitation and PDSI reconstructions. These records need to be expanded temporarily and spatially. There is much scope for future tree-ring based studies to establish longer chronologies from varied species at high altitude sites. The dendroclimatic potential of the taxa from the region was established (Hughes & Davies 1987, Bhattacharya et al. 1988) but the numbers of sample studied based on the various taxa are very limited (Hughes & Davies 1987, Bhattacharyya et al. 1988, Borgaonkar et al. 1994). Moreover, the datasets studied earlier (Hughes & Davies 1987, Borgaonkar et al. 1994) have been used repetitively in various studies and lack new samples (Hughes 1992, Hughes 2001, Ram, 2012, Ram & Borgaonkar 2013, Ram & Borgaonkar 2014). The tree-ring chronology length prepared so far from the valley is varying from 117 to 373 years. However, adjoining areas of Kashmir Valley recorded 400 to 500 years long ring-width chronology (Bhattacharyya et al. 1988).

An understanding of the tree-ring studies on conifer taxa in the Kashmir Valley and reconstruction of other records such as fire history, stream flow, snowfall, glacial fluctuations, earthquake and other related aspects have tremendous scope in this high altitude region. The conifer species growing in the valley have been established to record such phenomenon in their tree-ring records in other part of the Himalaya (Bhattacharyya & Shah 2009, Brown et al. 2011, Shah et al. 2013, Shah et al. 2014a). Also, there is a lack of similar tree-ring based records that try to study the spatio-temporal variations linked to environmental factors in the region.

The Kashmir Valley is drained by river Jhelum and its tributaries and each tributary forms a catchment of Jhelum Basin. The valley is host to major river systems and stream flow data that can be extended beyond the instrumental record on the basis of tree-ring data. This will certainly contribute to future planning and regulation by the authorities in this vastly populated region of northwest India. Reconstruction of the precipitation and drought in a wider spatio-temporal scale beyond the available instrumental records may also help in modeling the impact of seasonal and annual hydro-climatic variability. The valley has high snowfall during winter months of the year and certainly impacts the climate and vegetation distribution in the region. The Kashmir Valley has an instrumental record of snowfall up to the years 2000-2012 from various metrological stations (Indian Meteorological Department, Pune). Thus, there is a possibility to reconstruct (in detail) the snowfall in the valley based on future tree-ring studies.

The high altitude regions of Kashmir Valley have many glaciers, which are source of snow melt water that feeds the river systems of the valley. It is imperative that the models based on tree-ring data, can reconstruct the variations in stream flow due to the snowmelt during early summers. These reconstructions could segregate the impact of snowmelt and rainfall on the stream flow annually and identify the dominant source in the river system. This shall subsequently deduce the significant tree growth pattern and its variation due to seasonal precipitation (snow melt or rainfall). This snowmelt is also responsible for variations in the soil moisture along the slopes and hence shall affect the tree growth patterns. There are established relationships of fluctuations in glaciers originating in western Himalaya with tree-ring data (Bhattacharyya & Yadav 1996, Bhattacharyya et al. 2006). The variation in growth patterns *Betula utilis* and *P. wallichiana* have been related to advancement and retreat of Gangotri (Bhattacharyya et al. 2006) and Kinnaur (Bhattacharyya & Yadav 1996), respectively. Such glacial activities can also be established in tree-ring records from Kashmir Himalaya. In addition, glaciers fluctuations can possibly be recorded using tree-ring data from the region that has many glaciers viz., Kolahoi, Thajwas, Seshnag and glaciers of the Pir Panjal Range.

The Kashmir Valley lies in the vicinity of tectonically sensitive zones of Himalaya and has witnessed major earthquakes in the past (Sinvhal 2011). Tree-ring records from other parts of Himalaya have recorded some of the major earthquakes (Yadav & Bhattacharyya 1994, Bhattacharyya et al. 2008). Tree-ring studies in the Kashmir Valley also have a scope of capturing such earthquake signals especially in the higher altitude areas. The dendro-geomorphology is another aspect which has been untouched in the entire Himalaya. However, an exploratory dendrogeomorphological study in relation to avalanche events was recently undertaken in adjoining region of Lahul Himalaya (Laxton and Smith 2009) that helped in identifying four avalanche events during the period 1972 to 2006. Moreover, the variations in recent landforms due to tectonic and fluvial activities can also be clearly recorded in conifer taxa growing on the slopes of the mountainous terrain. The entire Himalaya including Kashmir Valley have records of such geomorphological variations in the tree taxa, which need further examination.

The tree-ring data can also be used to generate spatial climate reconstruction using various techniques under Climate Field Reconstruction with the help of widely used technique of point-by- point regression (Cook et al. 1999). Such studies are lacking in the Kashmir Valley. The tree-ring records from Kashmir also lack studies that help establish tele-connections with regional and global environmental records such as El-Niño Southern Oscillations (ENSO), Sea Surface Temperatures indices and others. Tele-connections have been established based on tree-ring records from similar species in the adjoining regions of Himalaya (Thapa et al. 2015). The Kashmir Himalaya has a strong influence of the western disturbances originating in the Mediterranean (Dimri et al. 2015). It is important to reconstruct rainfall resulting due to these climatic influences to understand the prevailing precipitation pattern. Tree-ring data can also preserve the signals of these sources of variation in precipitation annually on a longer time-scale.

There are few sites in the Kashmir Valley where left-over stumps of conifer taxa mostly *A. pindrow* are available, which could provide opportunity to extend the tree-ring chronology length (Text figure 5). Apart from conifer taxa studied for the tree-ring, broad-leaved taxa such as *B. utilis* growing at the tree line of the valley also produces annual ring and is a promising taxa for undertaking future tree-ring studies. However, few studies in other parts of the Himalayan region have used *B. utilis* (Bhattacharyya et al. 2006, Dawadi et al. 2013, Liang et al. 2014).

The annual ring producing tree taxa growing in Kashmir Valley provides great opportunity for tree-ring research in relation to climate reconstruction and evaluation of environmental phenomenon on a spatio-temporal scale in the recent millennia.

Text Figure 5. Left over tree stumps of *Abies pindrow* in high altitude area of Lidder Valley. Field photograph by authors during field visit of 2015.

Thus, it is reiterated here, that there is immense scope of dendrochronological studies in the Kashmir Valley.

CONCLUSION

The present review shows that the conifer taxa such as *Cedrus deodara, Abies pindrow, Picea smithiana, Pinus willichiana* and *Pinus girardiana* growing in the Kashmir Valley has great potential for the reconstruction of past climate, especially to reconstruct seasonal variation of temperature, precipitation and drought. The broad-leaved taxa such as *Betula utilis* growing at the tree line of the valley produce annual ring and should be incorporated more often for tree-ring analysis along with coniferous taxa in future studies. The maximum spatial coverage of tree-ring network with maximum samples shall provide a more lucid understanding of the spatial and temporal variation in past climate and drought scenario of the Kashmir Valley, where instrumental records are available for a very short time period. We emphasize that the extensive work needs to be carried out on tree-ring based reconstruction and other phenomenon such as stream flow, glacial fluctuations, past earthquake records, fire history and geomorphic evidences in the near future.

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