Climatic Response of Himalayan Silver fir *(Abies spectabilis)* from Tree Line of the Dolpa, Northwestern Nepal

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Abstract

Identifying the relationship between climate and tree-ring growth is a basis for the climatic reconstruction using tree-ring as proxy of past climate. Himalayan Silver Fir (*Abies spectabilis*), an endemic species of the Himalaya, is one of the potential species for dendroclimatological studies. In this communication, we report the growth responses of *A. spectabilis from* marginal area to climatic parameters using tree-ring chronology. A total of 102 tree core samples from 90 trees were collected from nine quadrats of 20 m × 20 m size located along elevation gradient between 3590 m and 3730 m a.s.l. in Dolpa district of Nepal. A 235–year long tree–ring width chronology of *A. spectabilis*, dating back to 1777, was developed. A quantitative analysis between tree growth and climate, based on a correlation and response function showed that the radial growth of the species was mainly limited due to temperature induced moisture stress during spring season having negative relationship with mean maximum temperature of March ($r^2 = 0.43$, $p < 0.05$) and May ($r^2 = 0.55$, $p < 0.01$), and mean temperature of May ($r^2 = 0.43$, $p < 0.05$) of the current year and positive relation with the precipitation of the same season. If the current scenario of rapid increasing trend in temperature and decreasing trend in precipitation will continue in the region, it will have an adverse implication in the growth of the species with future climate change.

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Introduction

Width of tree rings of any tree growing in a particular location is influenced by climate. Analyses of tree rings from high altitudes and latitudes provide a way to extend back the climatic information beyond the instrumental record (Fritts 1976; Speer, 2010). Examination of the annual growth rings of a tree not only reveal its age, but also the fluctuation in climatic conditions during its lifetime (Dayton, 2003). Therefore, dendroclimatology has been an effective tool for analyzing the ecological relationship between tree growth and climate (Fritts, 1976; Speer, 2010) Knowledge of the past climatic variations and their impacts will be necessary for the better understanding of climate change in the future. Recent climatic change has been affecting the distribution, physiology, and phenology of some species which is consistent with the theoretical predictions from long term data from the past half century (Hughes, 2002; IPCC; 2014). Most of the dendrochronological studies support the long-term monitoring of the impacts of climate change on tree growth. Although several studies are focusing on the causes of rapid glacier retreat and tree line shift using different ecological approaches, a long-term climatological data is essential to get appropriate results (Bhattacharya *et al.*, 1992; Shrestha *et al.*, 1999; Gaire *et al.*, 2014). In Nepal, there are about 200 weather stations distributed throughout the country but most of the stations were established only after 1960 for precipitation and 1970 for temperature measurement (Shrestha *et al.*, 1999; Shrestha *et al.*, 2000). It signifies the lack of comprehensive meteorological data for statistically calibrating tree ring series and conducting long-term climatic studies. Some tree species in Nepal such as *Pinus wallichiana, P. roxburghii, Abies spectabilis, Cedrus deodara, and Juniperus recurva* have been found promising for dendroclimatic studies (Bhattacharya *et. al.,* 1992; Cook *et al.*, 2003; Gaire *et al.*, 2013).

Nepal has a wide geographical and climatic variation ranging from tropical to alpine regions which provides the scope for dendrochronological studies in its high mountains and in the Himalaya. Dendrochronological study began in Nepal in late 1970s by Rudolf Zuber who collected tree ring samples from different species occur in various habitat types. Suzuki (1990) and Bhattacharya *et al.* (1992) studied several trees and find the potentiality of different species for dendroclimatological studies. However, dendrochronological studies from Nepalese Himalayas still are rather few and incomprehensive (Sano *et al.*, 2005). Most of the Dendrochronological studies are focused mainly on Central and Eastern part of the country such as in Langtang National Park, Kathmandu Valley, Ganesh Himal, Mustang, Manaslu, Sagarmatha National Park (Gaire *et al.,* 2013). Few studies have been carried out in the Far-Western and Mid- Western part of Nepal such as Humla (Sano *et al.*, 2005), Rara lake and Jumla (Suzuki, 1990; Cook *et al.*, 2003) Dolpo (Brauning, 2004) covering very limited areas and site. Many studies were focused on dendroecology mainly on tree line dynamics, few studies are focusing on tree growth to climate relation analysis (e.g. Chhetri, 2008; Udas,2009; and Gaire *et al.*, 2011, 2014), but very few research on climatic reconstruction were carried out (Cook *et al.,* 2003; Sano *et al.,* 2005; and Thapa *et al.*, 2014). In the present study, we collected samples of *Abies spectabilis* from north-western part of Nepal at Dolpa District. In Nepal Himalaya, it is most abundant in Humla District found either in a single stand or with other taxa such as *Picea smithiana* and *Betula utilis* (Stainton, 1972). Despite of its abundance in western Nepal, only few preliminary attempts have been made till date to explore the dendroclimatic potential of this taxa. This study was carried out to extend the scientific information in western Nepal Himalaya with objectives; to develop the tree-ring width chronologies and characterize their responses to instrumental measurements of temperature and precipitation, and to contribute new chronology in the existing tree ring chronology network from Nepal.

Materials and Methods

Tree core samples of *Abies spectabilis* for this study were collected from the Toridwari Community Forest of Majhphal Village Development Committee (VDC), Dolpa, during August 2011 (Fig. 1). The sampling site (28°89’ to 28°88’ N and 82°79’ to 82°87’ E) lies in timber-line forest between 3592 and 3728 m a.s.l. on northeastern facing slope of the trans-Himalayan region. The forest stands had no sign of fire and landslide in the recent past but comprised few stumps. The abrupt type of tree line was found in the study site. The climate of the study area has very cold winter and relatively warm summer. The mean annual rainfall is 348 mm. The maximum temperature in summer is 29 °C in July and that in winter is very cold with freezing temperatures down to negative 2.5 °C in January as measured in the weather station located in Dunai (Fig. 2). The subsidiary ridges of *Abies spectabilis*, where the sampling was conducted, were covered by mixed *Caragana arborescens*, *Betula utilis*, *Rhododendron* spp., *Ephedra Gerardiana*, *Rosa sericea* and other coniferous plants. The study site was divided into three vertical belt transects at North-east facing slope. The horizontal distance between adjacent transect was 300 m from each other's. Each quadrat of 20 m × 20 m size was laid from the uppermost limit of the *Abies spectabilis* at tree line towards lower elevation region. In each transect, three quadrates were laid in 50 m distance from each other to collect samples. Thus, total nine quadrats were established in the study site. In each quadrat, geographic position, elevation, aspect, slope and canopy coverage were recorded.

Sample collection and processing

The tree core samples were collected and analyzed by following the commonly used dendrochronological procedure (Fritts, 1976; Speer, 2010). A total of 10 tree core samples were extracted by an increment borer (Haglof, Sweden) from each quadrat. The sample core was extracted at breast height (about 1.3 m above the ground) and parallel to the contour of the slope. 102 sample cores from 90 trees of *Abies spectabilis* were collected among them 45 cores were successfully cross-dated. Samples were wrapped with blotting paper for water absorbtion and labeling it. After returning back from the field (15 days later), the sample cores were glued into a wooden frame, wrapped by paper-tape and allowed air dry for a week. Those cores were then sanded by using different grades of sanding paper (80, 120, 240, 300, 340, 400, and 600) until cellular structures and tree ring boundaries been clearly visible under the microscope. The ring of the core was counted with the help of stero-zoom microscope (LEICAS$_4$E) in the Dendro-Lab of Nepal Academy of Science and Technology (NAST), Khumaltar, Lalitpur. After counting the number of rings, the ring width of each sample was measured with an accuracy of 0.01 mm using a moving ring width measuring stage LINTAB5, attached to PC having a computer program TSAP-win (Rinn 2003). The alignment plotting technique was used for cross-dating of the samples that may have missed or false rings. Then quality of the cross dating and measurement was further checked with the help of COFFECHA program which again identifies occurrence of any further errors (Holmes,1983). The tree-ring series with errors shown by COFFECHA were either corrected or excluded in the final analysis. 57 tree-ring series, which were very young (less than 50 years old) and the correlations < 0.32 with the master series, were excluded (Fritts, 1976).

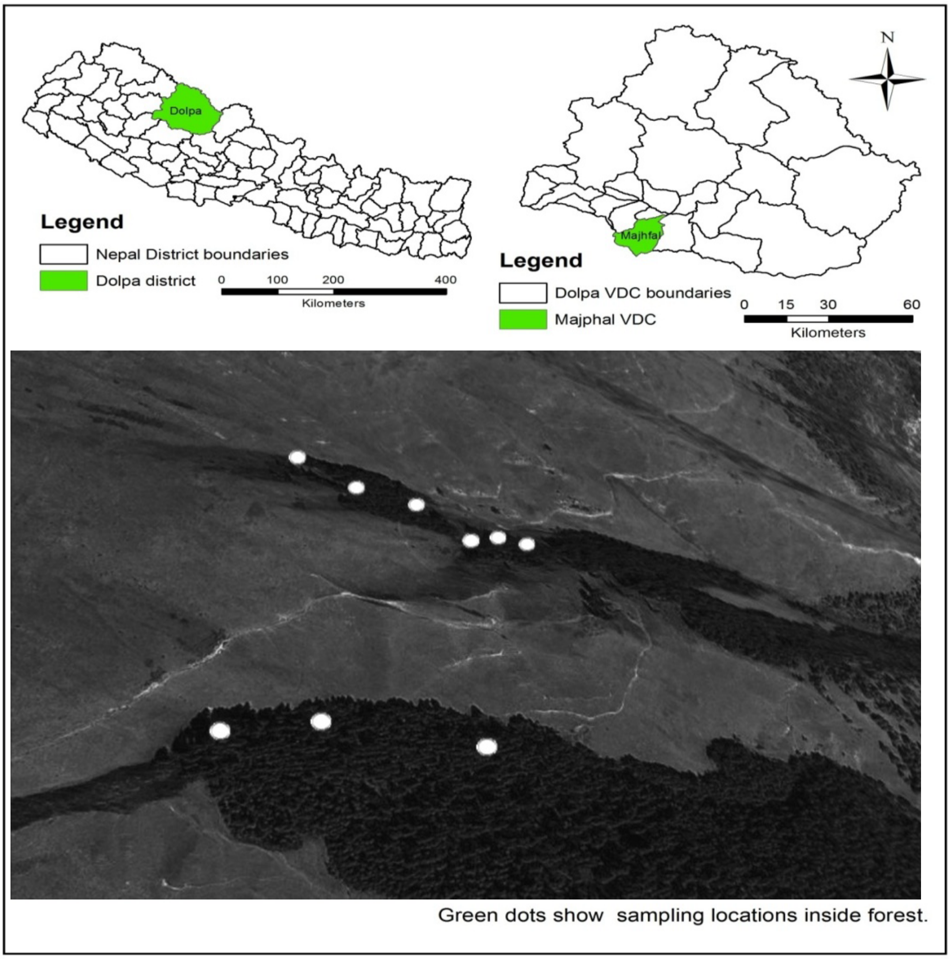

Fig. 1. Geographical location of the study site.

Standardization and chronology development

The ring-width data were standardized by using the negative exponential curve using ARSTAN program and three types of chronologies (standard, residual and arstan) were developed (Cook, 1985). The chronology considered suitable for climatic study should have a good correlation in both between trees and within trees, high mean sensitivity, high standard deviation, high values of common variance, and high signal-to-noise ratio (Fritts, 1976). Chronology statistics like mean tree ring width, mean index, standard deviation, standard error, autocorrelation, mean sensitivity were calculated to assess the quality of the chronology for the dendro-climatic information. Mean sensitivity is a measure of the relative difference in width between consecutive rings (Fritts, 1976). Its possible values range from 0 (indicating no change in ring width from one year to the next) to 2 (occurrence of missing ring), with high mean sensitivity measurements interpreted as an indication that the ring-width series may have dendroclimatological utility

(Fritts, 1976). First-order autocorrelation is a measure of the degree to which a given year's growth is correlated with the preceding year's growth. Theoretically, there is an inverse relationship between mean sensitivity and autocorrelation (Fritts, 1976). Mean series correlationis used to determine the similarity of the individual ring width series in a chronology. It is calculated for within trees, between trees and among all the radii. Signal to noise ratio is a measure of the common variance in a chronology scaled by a measure of the total variance of the chronology. (Wigley *et al.*, 1984) has suggested an Expressed Population Signal (EPS) value of 0.85 as an acceptable value demonstrating a strong common signal present in a chronology.

Responses to climatic variables

In order to find the response of tree growth to climate, response analysis was performed. For this purpose it is desirable to use climatic data from the study site. Climatic data of the weather station located near to the study site in Dunai, Dolpa were obtained from the Department of Hydrology and Meteorology (DHM); however, the climate (temperature and precipitation) record of that station was only 14 years long (1991 to 2005; station closed after 2005). It was too short, with some values were missing for both temperature and precipitation, for meaningful response analysis. Therefore, the climatic data from another station located in Jumla, which lies towardsthe north-west of the sampling site at a distance of about 45 km, were used. The missing values were interpolated by averaging the mean monthly data throughout the years (Bhattacharya & Chaudhary, 2003). To confirm the validity of this substitution, correlation between Dunai station and the respective climatic data of Jumla were examined. It showed a significant correlation with both precipitation and temperature. Correlation analysis was used to examine how climatic variables (monthly mean temperature and monthly total precipitation) and the radial growth varied (Fritts, 1976). The standard tree ring chronology revealed good correlation with climatic data of Jumla station than of Dunai for the period for which the data is available from Dunai. To analyze previous year's climatic influence on the growth, last four months (September-December) of the previous year were also taken. In the present study, the tree ring chronology was constructed from the year 1777 to 2011. Since the climatic data was available for the period of 1979 to 2011, the standard chronology of the same period was taken to establish relationship between tree ring growth and climatic data of Jumla station. This period was selected because the conditions during the previous and current year growing season can affect the amount of carbon fixed and allocated to tree growth (Fritts, 1976; Harley *et al.,* 2011).

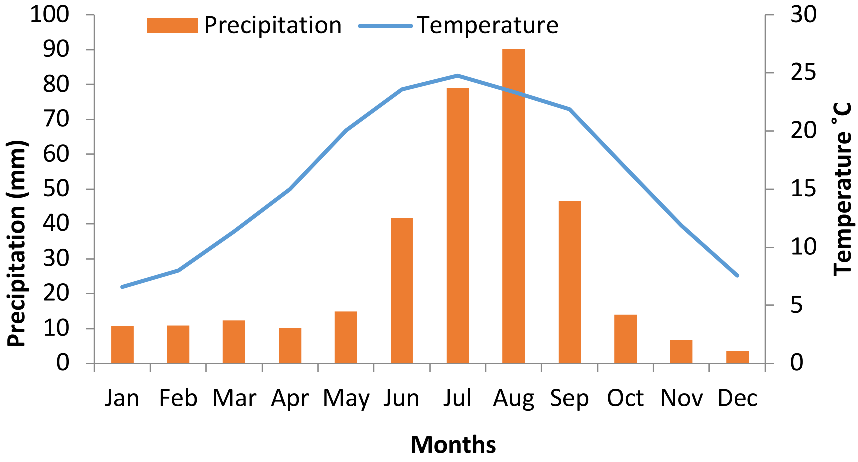

Fig. 2. Climographs for a Dunai station, Dolpa (1991-2005). Data were obtained from Department of Hydrology and Meteorology of Nepal.

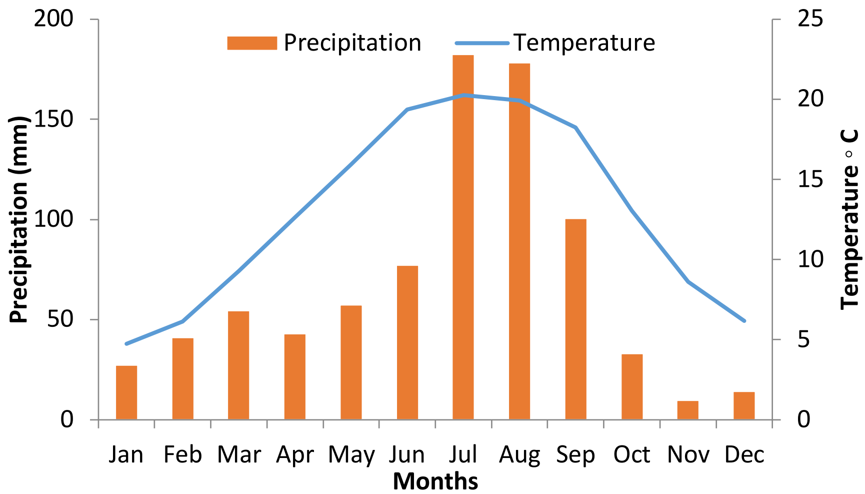

Fig. 3. Climographs for a Jumla station (1979-2011). Data was obtained from Department of Hydrology and Meteorology of Nepal.

Results

Tree ring chronology statistics

The pointer years common for some rings were recognized in every 2 or 3 decades (Fig. 4). The 235-year long chronology of *Abies spectabilis* was prepared from 45 samples, which extends from 1777 to 2011 (Fig. 4). From 1777 onward the tree ring showed wider ring in the pointer years 1788, 1792, 1809, 1831, 1847, 1917 and 2003 whereas the tree ring was narrow in the pointer years 1797, 1805, 1836, 1842, 1870, 1891, 1984 and 1999. From 1846 onward the growth pattern of tree rings was fluctuating. Mean radial growth was 0.996 mm per year (*SD* = 0.136).

Table 1. Selected statistics of tree-ring chronology of *Abies spectabilis* at Dolpa.

Chronology statistics	**Standard**	**Residual**
Chronology-period (Years)	1777-2011	1777-2011
Standard deviation	0.141	0.116
Mean sensitivity	0.109	0.125
Serial correlation	0.542	0.124
1st lag auto correlation	1.0	2
Correlation between trees	0.230	0.204
Correlation within trees	0.750	0.628
Expressed population signal (EPS)	0.906	0.892
Signal-to-noise ratio (SNR)	9.672	8.287
Minimum sample size for the EPS 85%	19	13

Table 1 shows the chronological characteristics with some dendrochronological potential with moderate mean sensitivity, moderate first order autocorrelation, and high EPS value in standard and residual chronologies. The EPS value of 0.85 (i.e., 85%) is suggested as threshold limit (Wigley *et al.,* 1984) and it exceeds here in both standard and residual chronology (0.906 and 0.892 respectively) (Table 1). The values of mean correlation within tree in both standard and residual chronology were high (0.750 and 0.628, respectively) as compare to mean correlation between tree and among all radii (Table 1). Both the residual and standard chronologies of ring width constructed since early 1777 satisfied the minimum threshold value of EPS.

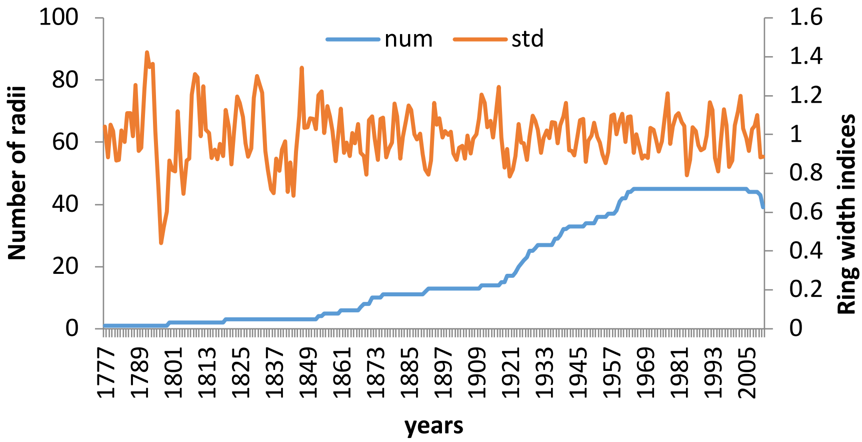

Fig. 4. Chronologies of tree-ring widths of *Abies spectabilis* between 1777 and 2007.

Climate and tree growth relationship

The mean maximum temperatures of May and March of current year showed statistically significant but negative correlation with radial growth of tree ring (Fig. 5). Likewise, a significant negative correlation was found with mean temperature of May (Fig. 6). There was a positive relationship between the radial growth and precipitation though not significant statistically

(Fig. 6). The relationship between the CRU gridded PDSI covering study area and growth was also tested. There was a positive relationship between the growth and PDSI, however, not significant statistically.

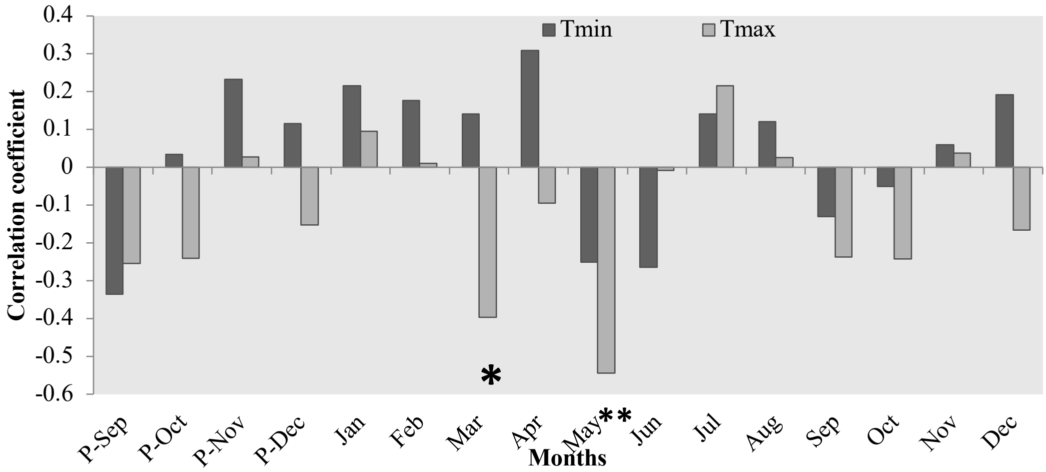

Fig. 5. Correlation between standard chronology and monthly minimum and maximum temperature. Note: ** Significant at $p < 0.01$, * Significant at $p < 0.05$. The months with 'P' represent the months of previous years, for e.g. P-Sep = Previous September……, Jan: January, Feb: February………Dec: December).

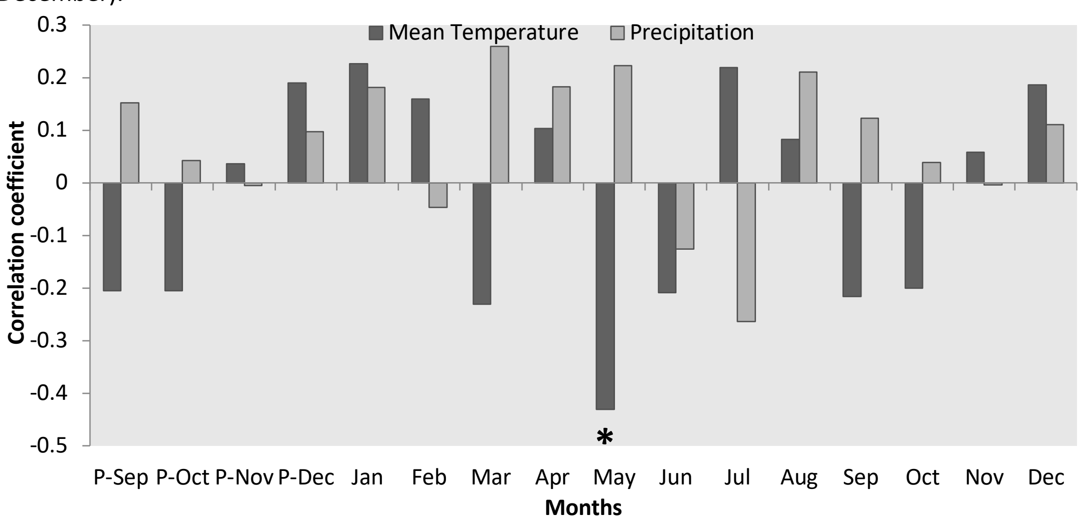

Fig. 6. Correlation between standard chronology and monthly mean temperature and total precipitation.

Discussion

Tree ring chronology

The tree ring chronology of *Abies spectabilis* developed in the present study was extended back to 1777 AD (235-year). The length of core was limited by the small size of the increment borer (12 inch); however, in Nepal longer chronologies from *A. spectabilis* have been developed by various researchers: from 1700-1980 by Bhattacharya (1992); from 1395-1997 by Cook *et al.,* (2003); from 1717-2000 by Sano *et al.,* (2005) etc. Since we sampled only at tree line ecotone, there could be older trees spanning longer age in the middle and lower part of the forest. Some pointer years recorded in the present study are also observed in other studies (Sano *et al.*, 2005, Thapa *et al.*, 2013, 2014). The statistical analysis of standard chronologies from the *A. spectabilis* at tree line revealed relatively low mean sensitivity (<0.2), medium standard deviation values (0.2) but high first order autocorrelation values (>0.5). The value of mean sensitivity ranges from zero to two (0 - 2) whereas the lower mean sensitivity indicates lowest variance of frequency (Fritts 1976). The Expressed Population Signal (EPS) was clearly above the 0.85 threshold (Wigley *et al.,* 1984) in the site chronologies since 1892s. Hence, the high value of EPS confirmed that the chronologies developed for *A. spectabilis* in the study site showed a common signal and suitable for studying climate growth relationships. Other several studies in tree line also show similar patterns of growth (Gaire *et al.,* 2011, 2014; Udas 2009). One or more environmental factors are strong enough to cause the ring widths to vary in the same way (Fritts, 1976, 2001). Smaller scale responses of tree ring widths might be due to high competition between inter and intra-tree species present in the study area.

Trees at dry sites usually show higher inter annual growth variability than the trees from temperature limited sites (Fritts 1976, Bräuning 2001). But it is a typical for conifers which are growing in humid environments (Fan *et al.,* 2009). In subalpine temperate region, conifers have low mean sensitivity under moist sites rather than in arid sites (Bhattacharyya & Chaudhary, 2003). The chronology which has a low autocorrelation, a high mean sensitivity and a high standard deviation has been considered suitable for dendroclimatic analysis (Fritts 1976). Similarly, Bhattacharya & Yadav (1996) developed chronology of *Pinus wallichiana* tree ranging from 1621 to 1990 to study glacial behavior in the western Himalaya and concluded that tree growing in the subalpine Himalayan regions would be an excellent candidate for the tree ring study to understand past glacier behavior in the region. Thus, the northeast facing slope in the present study site could have a balanced supply of moisture. Low values of mean sensitivity have been reported from trees growing in the western Himalaya (Borgaonkar *et al.,* 1996) and the central Himalaya (Bhattacharya *et al.,* 1992). Similarly, the high value of first order autocorrelation (> 0.5) in the site chronologies revealed that the tree growth of the previous year had influence on tree ring widths of the current year. The high autocorrelation values reflected significant impact of previous year's climate on the current year's ring width, which could be due to carry-over effects of carbohydrates used for early wood formation (Fritts, 1976). A few studies have observed higher growth in the high-altitude tree ring chronologies during the past few decades in the other region of India Himalaya linked with the increasing temperature pattern over the region (Borgaonkar *et al.,* 2011); however, in the present study, there was no clear increasing tree growth in the recent years indicating site specific climatic response of conifers from Himalaya to climate change.

Relationship between tree ring and climatic variables

The climate growth relationship indicated that the growth of *A. spectabilis* in the present study is limited due to moisture stress during early growing season i.e., spring and early summer. Moist year with cool spring and early summer seems beneficial for the growth of the species. Correlation coefficients indicated that tree rings widths of *Abies spectabilis* were negatively correlated with previous year's late monsoon (September) and current year's pre-monsoon (March–May) temperature. The summer months in the study area starts from March and reach its peak at July then ends in September. During the pre-monsoon season, the precipitation is low and it coincides with the early growing season of the Himalayan conifers (Borgaonkar *et al.,* 1996, 1999). Due to high temperatures and low precipitation during pre-monsoon periods, it accelerates evaporation and evapo -transpiration resulting in moisture stress condition for tree growth even in mesic sites (Bhattacharya and Chaudhary, 2003). Similar results have also shown by Sano *et al.* (2005); Suzuki (1990), Thapa *et al.* (2013) in their studies from western Nepal and Gaire *et al.* (2011) from central Nepal. This relationship suggests that low temperature in the winter and moisture availability during pre-monsoon limits tree growth of this site. The cool and wet conditions during these months recharge the soil moisture, from which trees can take benefit for the next growing season. Tree growth is influenced by the climate of growing season i.e., March to September. Specifically, the ring width is mainly influenced by the climate of pre-monsoon seasons with some role of winter season. Sano *et al.* (2005) found that growth of the *Abies spectabilis* in Humla is controlled by pre-monsoon climate which was correlated negatively with temperature and positively with precipitation. It showed that the radial growth of *Abies spectabilis* in this region is mainly affected by temperature with the moisture stress during spring. Thus, reduced water availability during the beginning of growing season is restrictive for tree growth. Some reports mentioned that the rainfall pattern during the monsoon season over Southeast Asia is shifting the peak July rain to August (Lee *et al.,* 2009). Therefore, it can be presumed that the early monsoon brings only little rain prolonging the moisture stress conditions until July and inversely affecting tree growth even in the early monsoon season.

Temperature plays an important role during the growing season and low temperature can hamper tree growth due to reduced photosynthesis and thereby inhibiting regular physiological processes (Körner and Paulsen 2004)*;* however, sudden increase in temperature for a short period favours respiration over photosynthesis. As a result, there is loss of stored food (Körner & Paulsen 2004; Fritts, 1976). Therefore, these reasons seemed to be more supporting that the precipitation in the present study site has insignificant correlation with tree growth. While the temperature rises sharply from March through May, the rainfall lags behind by some months causing water deficit and suppressing tree growth. Similar response of ring width was also found in several coniferous species from the West Indian Himalayas too (Borgaonkar *et al.,* 1994, 1999, 2011). During March, temperature reaches fairly high for photosynthesis and the moisture induces rapid growth. Though the direction of relation in preset study dry site is in expected way, the weak relationship between precipitation and the growth of *Abies spectabilis* is due to sharp fluctuation of precipitation in different areas. The inverse relationship of tree ring width with May temperature might be due to lower net photosynthetic rate, resulted from the water stress. During this month, precipitation is almost negligible but temperature is at its maximum level. Hence, it appears that the pre-monsoon temperature has a vital role in the growth of coniferous trees of this region.A study carried out by Udas (2009) in Mustang on *Abies spectabilis* showed negative correlation with the month of previous year of December temperature and current year April-May-June temperatures in tree line whereas Fan *et al.* (2009) found that *Abies spectabilis* chronologies at high elevation of Hengduan Mountains in South West China were positively correlated with early winter temperatures (November -December); the results of the present study also support. If the trees ceased their annual growth prematurely, then the surplus photosynthate could be stored for immediate growth at the start of the next growing season (Henderson & Grissino -Mayer, 2009). There is site specific growth climate response in the Himalayas depending upon the prevailing temperature and precipitation regime. Few studies in the Himalayan areas showed that tree growth is limited by moisture availability in the pre-monsoon season with negative relationship with temperature and positive with precipitation (Suzuki, 1990; Borgaonkar *et al.,* 1996, 1999, 2011; Khanal & Rijal, 2002; Moinuddin *et al.*, 2009; Sano *et al.,* 2005; Thapa *et al.*, 2013, 2014), but in some sites, positive with current March-May temperature (Chaudhary *et al.,* 1999; Bhattacharya & Chaudhary, 2003).

Conclusion

A 235-year tree ring chronology dating back to 1777 AD was developed from *Abies spectabilis*. The chronology statistics show dendrochronological potential of this species. The response function analysis revealed that the pre- monsoon temperature plays an important role in growth of the *Abies spectabilis* in the study site. The mean maximum temperature of May and March of the current year shows a significant negative relation with tree growth patterns. High winter temperatures also positively favour the growth. The precipitation of that region shows a positive, though weak relationship with tree growth. This might be associated with the difference between the precipitation between sampling sites and climate station site.

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