Pak. J. Bot., 50(2): 579-588, 2018.

CLIMATIC UPSHOT USING GROWTH PATTERN OF *PINUS ROXBURGHII* FROM WESTERN NEPAL

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Abstract

The middle mountain of Nepal Himalaya is experiencing higher rate of temperature rise. A dendrochronological study was carried out to verify and record the impact of this warming by using the tree-cores of *Pinus roxburghii* Sarg. from Bicharichautara village of Syangja in Western Nepal representing a middle mountain of Himalaya with sub-tropical climatic zone. For this total 50 cores of *P. roxburghii* were collected from 30 trees. The standard methodology was used for sample preparation and analysis. A 165-year long chronology spanning from 1851 to 2015 AD was constructed from the cores. The result showed that the tree ring chronology of *P. roxburghii* in study site was positively correlated with pre-monsoon (March and April) rainfall and negatively correlated with the temperature of November of previous growth year and February, March and April of present growth year. However, the analysis of climate response to temperature revealed that there was a negative response of chronology for pre-monsoon season especially for monthly average temperature of April of current year whereas the response with rainfall was positive for pre-monsoon season, but they were statistically insignificant. From this study, it was concluded that the growth of *P. roxburghii* was limited by the pre-monsoon temperature particularly by April temperature. This conifer (*P. roxburghii*) has been recommended as a good choice of tree for the past climate study. The main problem with this species is that it contains several false rings and sometimes there is absent ring as well. To overcome such problems, a detailed study encompassing anatomical features to identify and locate false and missing rings is suggested.

Key words: Climate reconstruction, Pre-monsoon, Radial growth, Tree-rings.

Introduction

Global warming rate in the Himalaya and adjacent regions is several times greater than the global average (Shrestha & Aryal, 2011; Xu *et al.*, 2009). Several impacts of the climate change in various sectors in Himalaya have already been observed (Shrestha & Aryal, 2011; Xu *et al.*, 2009). According to Intergovernmental Panel on Climate Change (IPCC), even small change in mean or variance of climate variables may result several folds greater change in frequency and intensity of extreme events creating a challenging condition for the living organism to respond with adaptation (IPCC, 2013). In addition, the extreme events are expected to alter current and future ecosystem dynamics. The impact of climate change has been seen on species distribution, population structures, vegetation shifts, vegetation composition, phenology, and growing season in global scale (Carrer *et al.*, 2016; Gaire *et al.*, 2017a; Theurillat & Guisan, 2001; Ziaco *et al.*, 2014).

Nepal, a Himalayan country, is highly threatened by impact of climate change. The atmospheric temperature in Nepal has been increasing at a rate of 0.04 to 0.06 °C/year, with a higher rate than the global average (Shrestha & Aryal, 2011; Shrestha *et al.*, 1999). Nepal is more prone to climate change due to absence of long term instrumental climatic data, which has become a major problem of studying climate change in Nepal (Bräuning, 2004; Cook *et al.*, 2003). To overcome this situation several alternative tools can be helpful for the precise estimation of past climate. One of such alternative is dendrochronology, and dendroclimatology (Chhetri & Thapa, 2010; Cook & Kairiukstis, 1990; Fritts, 1976; Gaire *et al.*, 2013; Speer, 2010; Thapa *et al.*, 2014). Dendrochronology and its sub disciplines such as dendroclimatology use tree rings as a proxy because tree rings are an exceptionally valuable source of paleo-climatic information and can be used to reconstruct the yearly variations in climate that occurred prior to the interval covered by direct climatic measurements. In fact, dendrochronology can date the time at which tree rings were formed, in many types of wood, to the exact calendar year (Speer, 2010).

The species of the genera *Abies* spp., *Betula utilis*, *Juniperus* spp., *Pinus* spp., *Larix* spp., etc. have already been proven to have great dendrochronological potential by various literatures in Nepal (Bhattacharyya *et al.*, 1992; Bhuju and Gaire, 2012; Bräuning, 2004; Bräuning *et al.*, 2011; Chhetri & Cairns, 2016; Gaire *et al.*, 2013; Gaire *et al.*, 2017b; Kharal *et al.*, 2017; Shrestha *et al.*, 2015; Suzuki, 1990; Thapa *et al.*, 2014; Thapa *et al.*, 2013; Tiwari *et al.*, 2017). Most of these species are distributed at higher elevation belt in Nepal, as a result most of the dendrochronological studies in Nepal are confined to higher elevation belt with temperate climate (Gaire *et al.*, 2013). Unlike previous studies this study is confined to the subtropical region of Nepal which contains more forest cover.

Pinus roxburghii Sarg. is a native tree species from the foot hill of the Hindu Kush Himalaya region. This species spread over Bhutan, China, India (Assam, Himachal Pradesh, Jammu-Kashmir, Sikkim, Uttar Pradesh), Nepal, Pakistan, ranging from 400 m to 2300 m a.s.l. in dry south facing and well drained area (Farjon, 2011; Polunin & Stainton, 1984). Generally, this species is found in Western Nepal in all aspects but in Central and Eastern Nepal it is generally found in well exposed southern slopes. It can grow reasonably well in almost all type of soil (Jackson, 1994). *Pinus roxburghii* generally forms pure stands but in far West at higher altitude it may be associated with *Olea ferruginea*, *Pistacia* spp., and other species of Mediterranean affinity (Jackson, 1994). Bhuju & Gaire (2012) found the species suitable for dendrochronological study with distinct annual rings. *Pinus roxburghii* is one of the most important tree species for the local people. It is economically important species since it offers timber, resins, wood for local people. According to the study by Department of Foesr Research and Survey (DFRS), this species occupies 8.54% of total forest cover in Nepal (DFRS, 2015). In terms of density, it is the fifth most dense tree species in Nepal having 7.05% of total stem volume in forest. Moreover, it possesses biomass of 9.90 t/ha in Nepal which accounts 5.09% of total woody biomass. To answer question related to growth-climate relationship and trend of climate change in past 100 years, this study was carried-out in a middle mountains range with subtropical climate.

Materials and Methods

Study area: The study area is a community forest in Bicharichautara village of Syangja District, which is in Panchase area (lattitude: 28° 8' 36'' N to 28° 18' 17'' N and longitude: 83° 43' 69'' E to 83° 59' 5'' E) of Western Nepal. The area of the community forest was about 4 hectares. Panchase is a pilot site for EbA project in Nepal, with total area 278.70 sq. km (Dixit *et al.*, 2015). Panchase forest is sub-tropical and temperate mixed evergreen forest extending from 1450 m to 2517 m elevation. Panchase represents a mountain ecosystem linking the lowland and high Himalayas of Annapurna Himalaya range with its characteristically rich natural and socio-cultural values. It has great diversity of trees. The higher part of Northern and Southern face of Panchase Hill is dominantly covered by *Rhododendron* spp., and *Quercus* spp. and the foot hill is dominantly covered by *Alnus nepalensis* and *Castanopsis indica*. The Southern slope is comparatively dryer and steeper with presence of natural stand of *Pinus roxburghii* at the foothill of Panchase. The Bicharichautara community forest is the nearest natural pine forest to Panchase protected forest, so it provides better opportunity to study the growth-climate relationship of that area and to generalize this result to regional scale (Fig. 1).

The climate of this area is subtropical to temperate. The meteorological data indicates that the mean maximum temperature in the Panchase area is about 29°C and the mean minimum temperature is 5.3°C (Dixit *et al.*, 2015). The coldest month is January with an average monthly minimum temperature of 4.3 °C. Monsoon (June, July, August and September) sees around 80% of the rainfall with an annual average rainfall of 3,355 mm which is well above the national average rainfall of Nepal (Fig. 2).

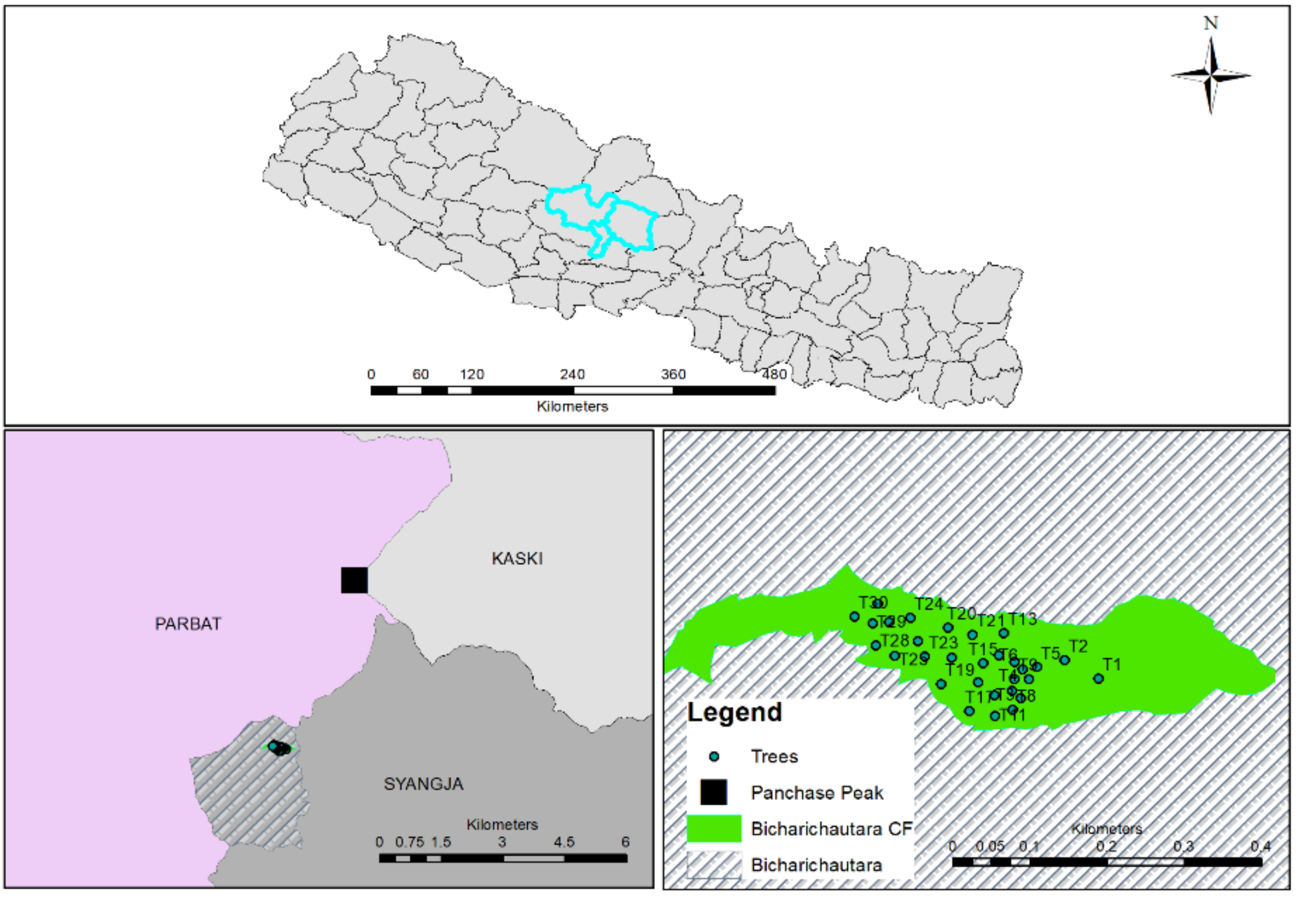

Fig. 1. Map of study area, Bicharichautara community forest, Syangja, Nepal with sampling location.

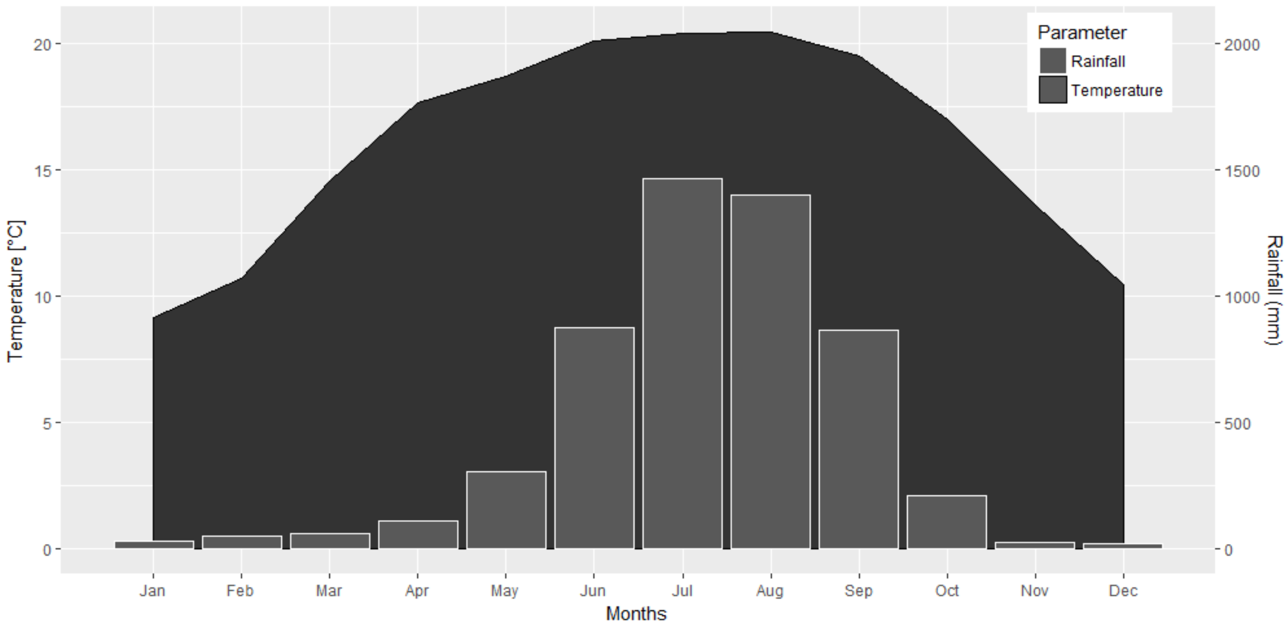

Fig. 2. The pattern of monthly average temperature and monthly total rainfall in Panchase, Western Nepal (data source: DHM).

Methods

Sample collection: In this study, in total 50 cores from 30 *Pinus roxburghii* were collected using increment borer (Swedish Haglöf 28´´, 3-Thread, 0.200´´ (5.15mm)). While extracting the cores some cores were not healthy or broken in several pieces therefore only 34 cores were used for tree ring measurement. The cores then were immediately kept in the plastic straw pipe with proper labelling. In addition, the GPS location, DBH and height of each individual tree was measured.

Laboratory and analytical methods: The cores were brought to the dendrochrnolgy lab of Department of Forest Research and Survey, Babarmahal, Kathmandu for lab analysis and were air dried for few days. Then the air-dried cores were mounted in wooden frame with transverse surface facing up (Speer, 2010). The cores then were sanded with sanding papers of grids ranging from 120-800 to make the surface smooth and visible annual rings. The cores with visible annual rings were dated to calendar year. Then, the tree-ring measurement was done using a hardware called LINTAB version 6 which come with a computer program TSAP (Rinn, 2003). Every single ring in each series was counted from bark towards the pith under the microscope adjusting the resolution for clear visualization. Ring width was measured at the resolution of 0.001mm (Speer, 2010). After the completion of ring width measurement, the individual tree-ring series were cross dated using the Alignment technique, looking the math graph and cross dating statistics as explained by Rinn (2003). The errors in the cross dating was rechecked and confirmed by using the computer program COFECHA (Grissino-Mayer, 2001; Holmes, 1983). In this study standardization was carried out applying a computer program ARSTAN (Cook, 1985). The detrending of each sample was done using negative exponential curve in order to remove the non-climatic age trends, i.e. low frequency variance (Cook & Peters, 1981). EPS cutoff analysis was done in dplR (Bunn, 2008) package based on R programming environment (R Core Team, 2016). The threshold EPS value was 0.85 and the running r-bar window was 32 years. This EPS cutoff analysis yields the chronology length which has EPS more than or equal to 0.85. The portion of chronology having EPS more than 0.85 is representative of population and which can be used for studying response and reconstructing climate.

Climate data: The temperature and rainfall data of Lumle Meteorological station ($28^0$18'N, $83^0$48'E) was taken from the Department of Hydrology and Meteorology (DHM), Kathmandu. Lumle station is situated at about 16 km far in north-east direction from the study area. The altitude of the station is 1740 m a.s.l. (Timilsina, 2015). Lumle is the place where the average annual rainfall is usually greater than the national average rainfall. In Nepal Himalaya it is very difficult to get more than 30 years long climatic data but in Lumle temperature and rainfall was recorded from 1969 AD. The 45 years long instrumental data of monthly average minimum, maximum temperature and monthly average rainfall was collected and used for growth-climate response analysis.

Assessing tree–climate relations: After the standardization and mean chronology development, the standard tree ring chronology of *Pinus roxburghii* was related with the instrumental climatic data recorded from Lumle meteorological station. For the correlation and response analysis statistical packages such as 'treeclim' (Zang & Biondi, 2015) and 'bootRes' (Zang & Biondi, 2013) were used based on R software (R Core Team, 2016). The correlation and response between tree ring chronology and monthly average temperature and rainfall was done from the month of August of previous year to the December of current year. The seasonal response was also analyzed using a function called 'seascorr' included in 'treeclim' which functions equivalently as the function 'seascorr' (Meko *et al.*, 2011) of MATLAB program (Zang & Biondi, 2015). Pearson's linear correlation coefficient was used as the indication of the extent of relationship between climate and chronology.

Results

Climatic description: The monthly pattern of rainfall and temperature was shown in Fig. 2. The pattern of temperature and rainfall correlated with each other. The monthly temperature and rainfall increase from March to July then the temperature gradually decreases to the winter in November-December. The trend of annual average minimum, maximum and average temperature are shown in Fig. 3. The trend of minimum temperature (Fig. 3C) was constant whereas the trend of maximum (Fig. 3A) and average (Fig. 3B) temperature was observed to be increasing with the rate of 0.056°C/yr and 0.028°C/yr respectively.

From the Fig. 3 it can clearly be seen that the pattern of both climatic parameters (temperature and rainfall) was opposite in most of the years. The drastic change in temperature and rainfall was observed. These years when the drastic fluctuation was occurred, were considered as event years. The total annual rainfall of study area was observed to be increasing with the rate of 8.9 mm/yr (Fig 3D).

Tree ring chronology: The individual raw tree ring series of 34 *P. roxburghii* cores showed some pointer years common in each series that provided the basic for the cross dating of the samples. The longest measured tree ring series was found to be 165 years long. The common interval in all series was measured to be from 1960-2015 AD.

Three types of standardized chronologies namely raw, standard and residual were obtained as shown in Fig. 4. The result of standardization shown in Table 1, demonstrates that the time span of standard chronology is 165 years extending from 1851 to 2015 AD. The regression coefficient of standard chronology within trees, between the tree and for all series were 0.568, 0.343 and 0.346 respectively.

The statistics of all standardized chronologies shows that the standard chronology is promising for further study of relationship between climate and growth of *P. roxburghii* in Panchase area. There was a strong correlation of the standard chronology with residual (0.96) and arstan (0.95) chronology as represented in Figs. 4 and 5.

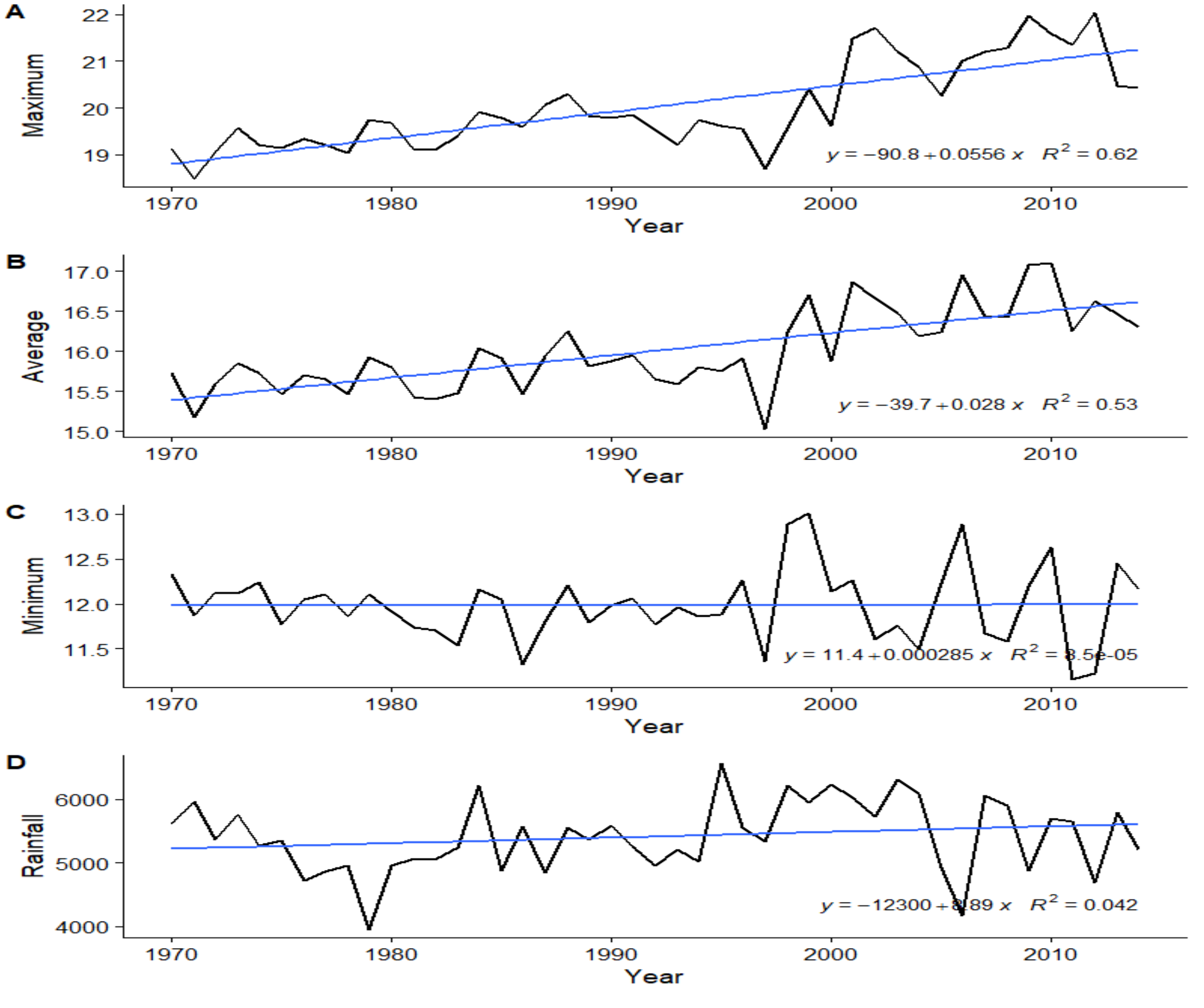

Fig. 3. Trend of temperature and rainfall in study site.

Table 1. The chronology statistics of *Pinus roxburghii* after standardization.

Statistics	Raw chronology	Standard chronology	Residual chronology
Average annual radial growth	1.998	0.973	0.996
Time span	1851-2015 (165)	165 years	165
Cores (Trees)	34(27)	34(27)	34(27)
Mean sensitivity	0.333	0.311	0.516
Standard deviation	1.059	0.252	0.465
Auto-correlation of 1st degree (Ac1)	0.685	0.010	-0.280
Common interval	1960-2015	1960-2015	
Running r-bar (all series)	0.305	0.346	0.380
Running r-bar (within tree)	0.557	0.568	
Running r-bar (between trees)	0.302	0.343	
Effective chronology signal	0.317	0.360	
Signal to Noise Ratio (SNR)	14.456	17.430	
Expressed Population Signal (EPS)	0.935	0.946	0.933

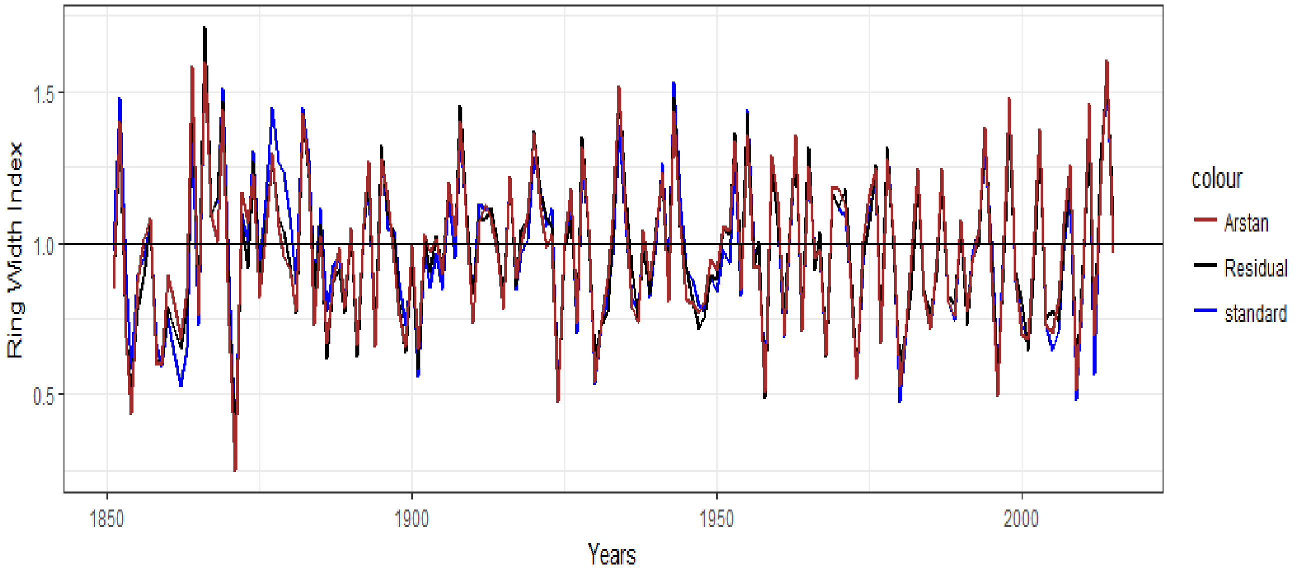

Fig. 4. Standardized chronology of *Pinus roxburghii* with sample depth of Panchase, Western Nepal (outcome of computer program ARSTAN).

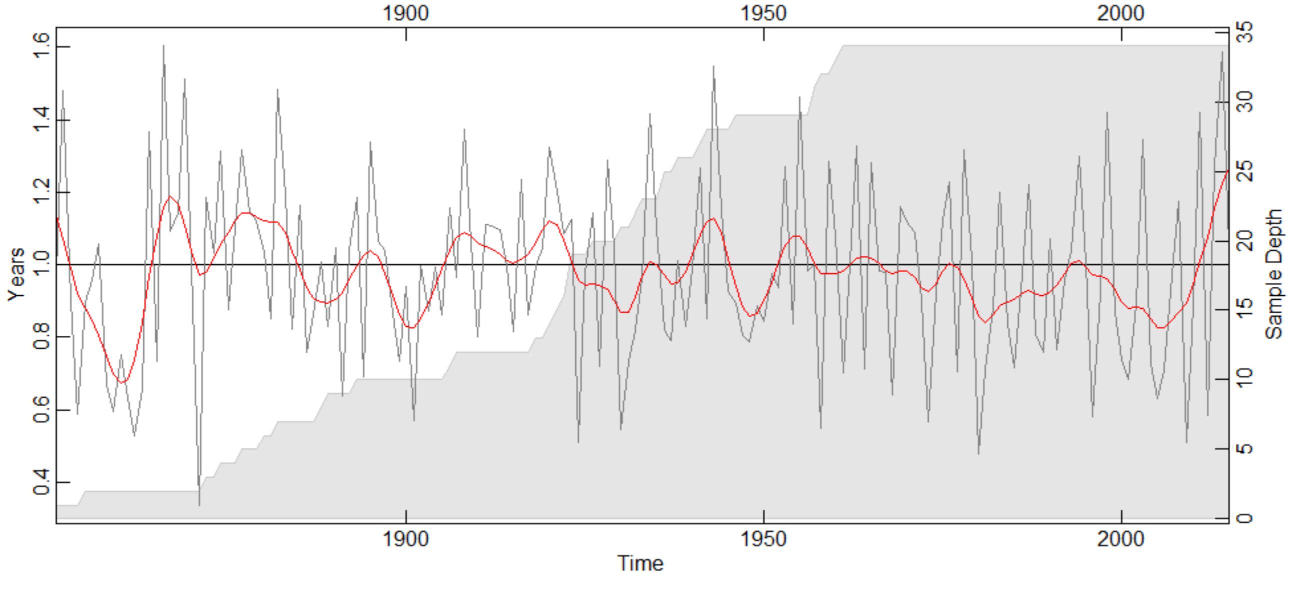

Fig. 5. The Standard chronology of *Pinus roxburghii* with red colored curve representing 10 years spline-smoothing curve.

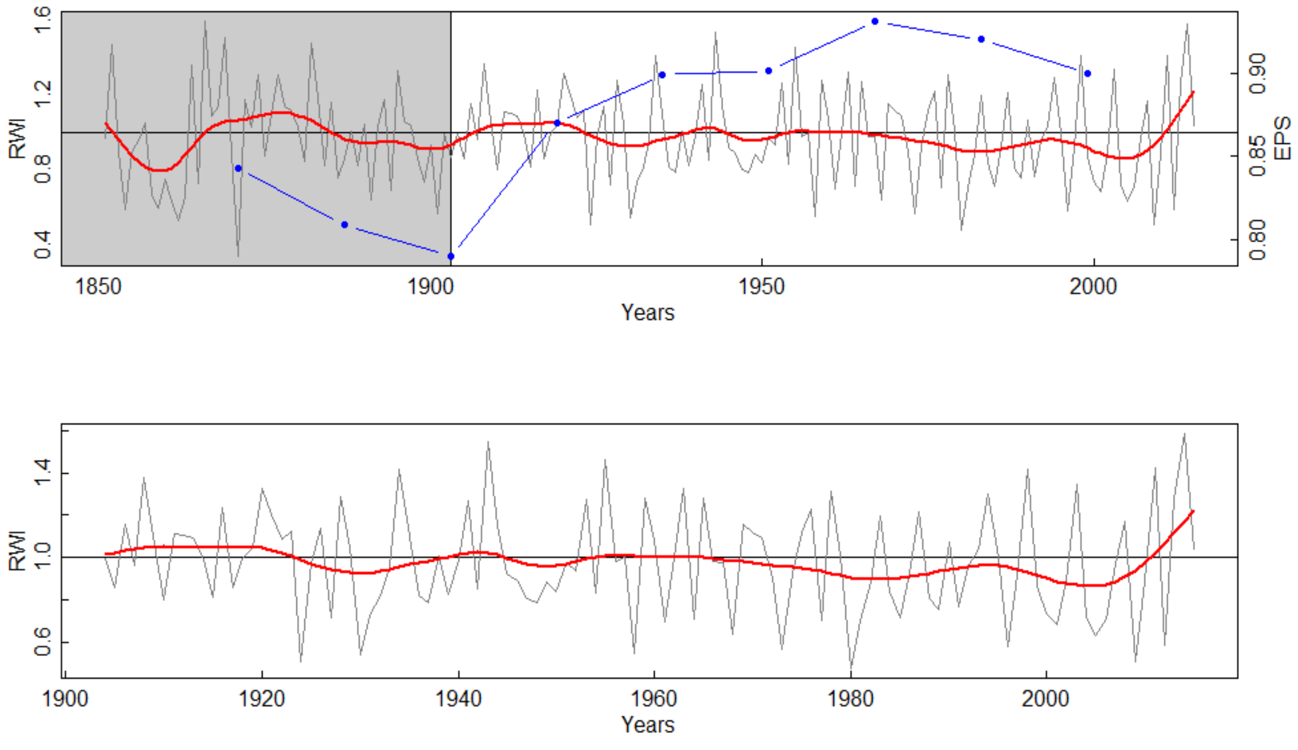

Fig. 6. *Pinus roxburghii* chronology of Panchase, western Nepal using an EPS cutoff.

To assess the standard chronology in depth, EPS cut off analysis was done taking 0.85 as threshold EPS value and 32-year window length the whole chronology was separated in two parts: one part having EPS less than 0.85 and vice versa (Fig. 6). The chronology of *P. roxburghii* in this study was 165 years long. The mean EPS was found to be 0.935 and sensitivity was 0.311 but only the period 1904-2015 AD was well replicated with EPS more than 0.85 (Fig. 6). The common period of the chronology was extended from 1960-2015AD which means the shortest sample chronology was 55 years old (1960-2015 AD). Among the three types of detrended chronologies (Fig. 4), standard chronology had low first order autocorrelation, so it was used for the climate reconstruction. The obtained chronology of *P. roxburghii* had mean EPS value 0.935. The mean sensitivity of the *P. roxburghii* chronology was calculated to be 0.311, which represents the year-to-year variability of chronology of *P. roxburghii* in Panchase. According to Speer (2010), it is good enough for the climate reconstruction. A study of the same species (*P. roxburghii*) by Shah *et al.* (2014) yield a chronology extending from 1891 to 2002 AD, the mean sensitivity and standard deviation of the chronology were 0.223 and 0.241 respectively. The first order autocorrelation was 0.229 which was removed using AR modelling. The EPS value of their chronology was under the threshold (0.85) and signal to noise ratio was 3.723. Beside (Shah *et al.*, 2014), few more similar studies have been conducted with same species. The studies by (Bhattacharyya, 1988) in India, Wahab (2011) in Pakistan and Bhattacharyya *et al.* (1992); Bhuju & Gaire (2012); Cook *et al.* (2003) in Nepal, attempted to study the potential of this species in dendroclimatic study. However due to poor chronology statistic the reconstruction was not performed yet.

Relationship between chronology and climate: The correlation between the climate data and tree ring chronology showed that there was significant negative correlation between temperatures of November (0.23) of previous year, February (0.23), March (0.27) and April (0.33) of current year with tree ring chronology whereas there was significantly positive correlation with rainfall of March (0.25) and April (0.24) (Fig. 7). However, the result of response function showed that the chronology had significantly negative response (0.286) only with April temperature (Fig. 8). The response with precipitation were statistically insignificant at $p<0.05$.

The result of seasonal correlation between tree ring chronology and climate of Panchase taking temperature as primary variable and precipitation as secondary variable is shown in Fig. 9. The seasonal response was done using resolution of 3, 4 and 6 months. The seasonal response analysis showed that there was significant negative response between tree ring chronology and pre-monsoon temperature of Panchase area.

The result has clearly shown that the chronology has significant negative correlation with the temperature of February-April, but the response of chronology is only seen in April temperature as depicted in Fig. 9. The chronology showed positive correlation with rainfall of April month. In addition to this the seasonal correlation shows that the chronology has significant negative correlation with the season of three months resolution with ending month in April. Response function differs from the correlation in a sense that response analysis incorporates bootstrapping, multivariate and principal component analysis (PCA) (Zang & Biondi, 2015).

Most of the studies conducted in Western Himalaya, using other conifers, have shown similar results that almost all the chronologies (Bhattacharyya, 1988;

Bhattacharyya *et al.*, 1992; Borgaonkar *et al.*, 1996; Sano *et al.*, 2005; Chhetri & Thapa, 2010; Dawadi *et al.*, 2013; Thapa *et al.*, 2013; Kharal *et al.*, 2014; Thapa *et al.*, 2014; Gaire *et al.*, 2017a; Gaire *et al.*, 2017b; Kharal *et al.*, 2017; Iqbal *et al*., 2017; Asad *et al*., 2017; Tiwari *et al.*, 2017) in Western Himalaya, North central-North Eastern India and in Northern Eastern parts of Pakistan, showed same negative correlation with pre-monsoon temperature. The study by Shah *et al.* (2014) of same species (*P. roxburghii*) in Parbati valley of India, got the similar result that chronology showed negative relationship with the pre-monsoon temperature and positive correlation with rainfall of prior year's November and current year's February-March, May and September. This indicates that moisture condition during pre-monsoon season is critical for the growth of the *Pinus roxburghii*. More precipitation during this period can be beneficial for the growth of the species whereas less precipitation may suppress the tree growth. As revealed from climatic data (Fig. 2) the study area receives 80% of precipitation in monsoon season (June-September) leaving rest of the months comparatively dry. The temperature starts gradually increasing from February and it exceeds the annual average during March. During the pre-monsoon season (March-May) the stress in tree is exacerbated by combined effect of high temperature and less precipitation, reducing the growth of tree (Borgaonkar *et al.*, 1996; Gaire *et al.*, 2017a; Kharal *et al.*, 2014; Tiwari *et al.*, 2017). In addition, drier condition is invited by the increasing evapotranspiration and drying of soil due to high temperature and low precipitation that limit tree growth (Dawadi *et al.*, 2013; Gaire *et al.*, 2017b; Kharal *et al.*, 2017; Liang *et al.*, 2012; Thapa *et al.*, 2014). Number of studies in Nepal Himalaya using other conifer like *Abies spectabilis* (Gaire *et al.*, 2014; Gaire *et al.*, 2017b; Kharal *et al.*, 2014; Kharal *et al.*, 2017; Sano *et al.*, 2005; Tiwari *et al.*, 2017), *Betula utilis* (Dawadi *et al.*, 2013), *Abiea pindrow* (Thapa *et al.*, 2013) and *Picea smithiana* (Thapa *et al.*, 2014), have also reported the similar (positive) correlation of the chronology with pre-monsoon precipitation. It may be due to the fact that cool and wet conditions during spring or early summer recharge the soil moisture that can benefit the trees by enhancing cambial activity during the growing season (Shah *et al.*, 2014).

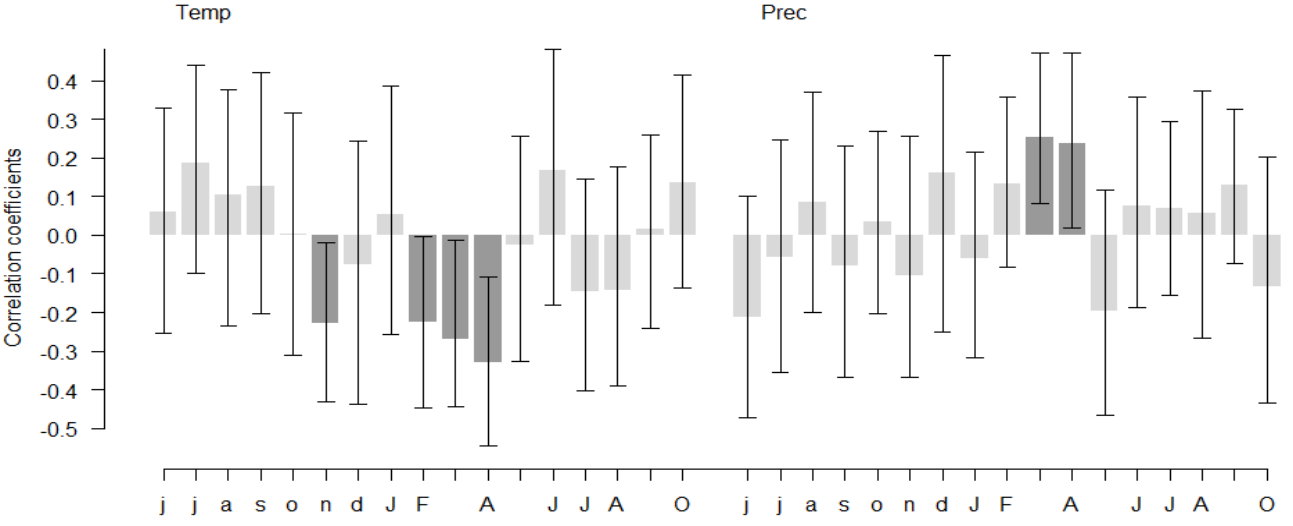

Fig. 7. Correlation between *Pinus roxburghii* chronology (standard) and climate of Panchase, western Nepal (at 95% confidence limit).

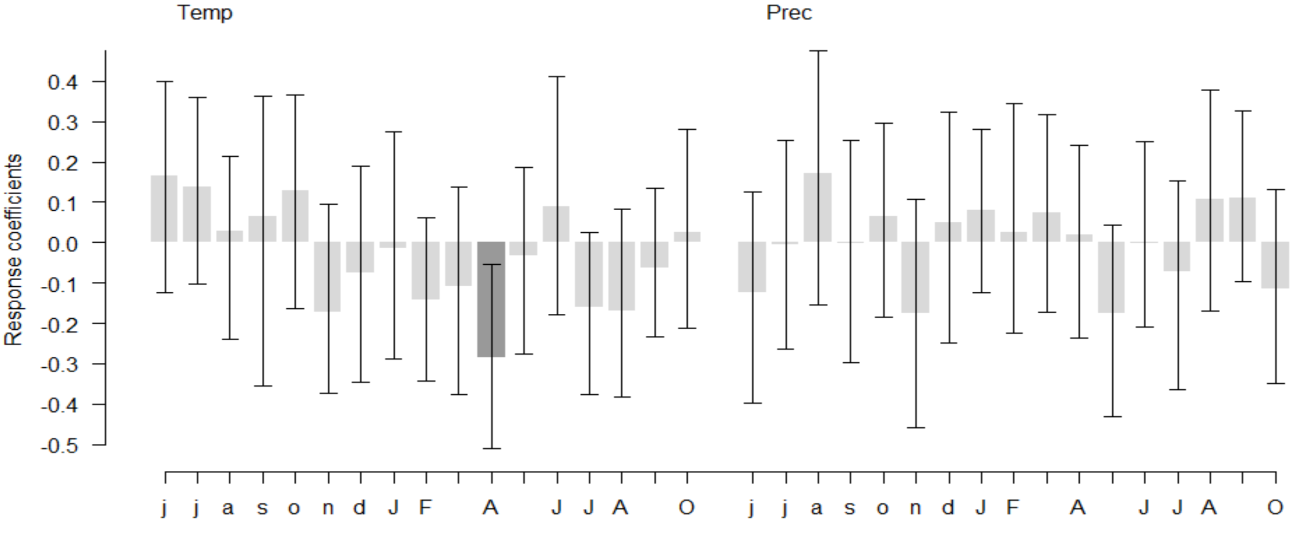

Fig. 8. Response between *Pinus roxburghii* chronology and climate of Panchase, western Nepal (at 95% confidence limit).

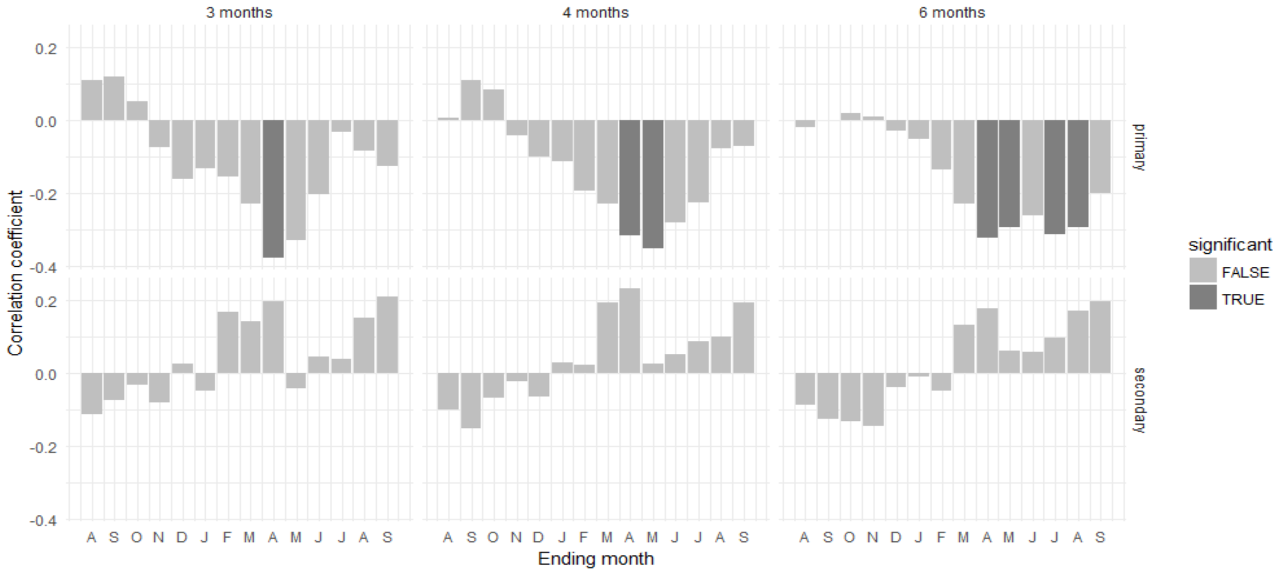

Fig. 9. Seascorr results summary of seasonal climatic signals in tree-ring data of *Pinus roxburghii* showing response of tree-ring variable with monthly, 3-month total, 4-month total and 6-month mean temperature for ending months from August preceding the growth (at 95% confidence limit).

Conclusion

Pinus roxburghii is a subtropical conifer inhabiting in dry and steep south facing and well drained slope of the Himalaya. The cross dating was quite challenging due to presence of number of missing and false rings. Despite the difficulties, 165 years long chronology of *P. roxburghii* was built extending from 1851 to 2015 AD. The chronology statistics were calculated to be promising for dendro-climatological study. The chronology of the studied species (*P. roxburghii*) showed statistically significant negative response to the April temperature and positive correlation with March and April rainfall. Moreover, the main difficulty in this study was presence of so called ‘False rings’. So, intensive research to identify ‘False rings’ using dendroanatomical approach can be helpful to make tree ring dating easy.

Acknowledgements

I wish to thank Ecosystem based Adaptation (EbA) Project for providing grant to accomplish my master’s thesis. I would like to express my gratitute to Nepal Academy of Science and Technology (NAST), Khumaltar, Lalitpur for funding for the publication of this research article. I want to thank Dr. Budhhi Raj Paudel and Dendrolab of DFRS, Babarmahal for providing permission to use lab and instruments. I would like to acknowledge everybody who directly or indirectly supported me to accomplish this research specially my friends Mr. Ramesh Younghang and Mr. Niraj Ghimire.

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(Received for publication 29 May 2017)