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Research

A Century Long Tree- Climate Relations in Manaslu Conservation Area, Central Nepalese Himalaya

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***Abstract**: Blue pine is an ecologically and economically valuable species that grows well in the Himalaya region. Detail knowledge of the growth response of this species provides key information for the conservation and management of the Himalayan ecosystem. This research aims to assess the dendroclimatic potential of Blue Pine to understand climatic effects on its growth. A growth analysis was done by taking two cores per tree from 35 trees. In which 31 rings from 20 trees were cross dated well to build more than a century-long chronology. Sample cores were collected and analyzed following standard dendrochronological procedures. At first, collected sample cores were mounted and sanded. The ring was counted and its width was measured by using LINTAB TMS. Cross dating was done by TSAP and cross-checked by using COFECHA software and tree ring width chronology was developed. After analyzing the 33 years long instrumental climatic data on a seasonal basis, the result showed that the growth was positively correlated with the precipitation of all seasons except post-monsoon. Similarly, growth was negatively correlated with the temperature of all seasons. Due to high temperature and low precipitation during pre-monsoon, this season was seen as the most drought stress condition for the growth of the Blue pine. This study could be the reference for the conservation and management of Himalayan ecosystem.*

***Keywords**: Blue Pine, Century, Dendrochronological, Drought, Pre-monsoon, Nepal, Himalayan Ecosystem*

Introduction

Climate change, a major global environmental problem, is also an issue of great concern to a developing country like Nepal, where the temperature is increasing at the rate of 0.04 to 0.06 0C per year since the 1970s, which is higher than the global average (Shrestha et al., 2012). Over the same interval, precipitation has become both more intense and irregular, with the region experiencing fewer rainy days on average (Karki et al., 2017). Despite its negligible contribution to the global greenhouse gas emission (0.027%). Climate change is likely to have a gloomy impact on the socio-economic as well as the natural systems of Nepal, affecting agriculture, livelihood, health, ecosystem processes, and vegetation. Studies have revealed that climate change has a more pronounced effect at a higher elevation (Shrestha & Aryal, 2011). Presently, the adverse effects of climate change are so rapid that they are almost irreversible and biological, social communities and other physical processes are not able to keep pace with these modifications. So, the study on climate change, its impact, mitigation, and adaptation are of high concern in Nepal. Many studies have been carried out focusing on the impact of climate change on agriculture, health and socio-economic sectors, whereas studies of its impact on forest vegetation and its response to the change are limited and little exposed (Shrestha & Aryal, 2011; Gaire et al., 2011).

The erratic rainfall and fluctuation of temperature over a long and short period will affect not only the economic potentiality but also the social and cultural contribution of the forest to the forest-dependent people making them vulnerable to the risk of climate change. Such impact of climate change on the forest are more clearly visible in the mountain regions of the country in the form of changes in species composition, invasion of non-native species, population structure, phenology and altitudinal shift of ecosystems (Carrer et al., 2014; Tiwari et al., 2016, Gaire et al., 2017) Moreover, IPCC report (2007) has projected that a sustained increase of 1°C in global mean temperature is sufficient to cause changes in regional climates affecting the growth and regeneration capacity of forests in many regions. Further, the report overviewed that the increased temperature may alter the function, distribution, and composition of forests significantly. Since large number of mountain community depends upon the forest resource it is utmost important to evaluate the likely impacts of projected climate change on forests i.e. how it responds to the changes based on its growth and distribution to decrease the potential risk. However, a paucity of long term instrumental climatic records is a major challenge to understand the impact of changing climate on Himalayan forest ecosystems (Cook et al., 2003). To overcome such a situation, dendrochronology and its discipline dendroclimatology has been the best alternative to understand the tree response to the climate, understanding the climate change impact and precisely estimating the past climate as well (Fritts, 1976; Cook & Kairiukstis, 1989; Chettri & Thapa, 2010). In this context analyzing long term climatic data i.e. temperature and precipitation records and correlating it with the width of tree's annual ring can give information on how the tree responds to the different climatic patterns on the past and what can be the possible impacts on the forest. The objective of this study was to build long tree ring chronology of Blue pine and to identify the relation between tree ring and climatic variables.

Materials and methods

Study species:

Blue pine (*Pinus wallichina* A.B Jaction) is a large evergreen tree native to Himalaya and widely distributed in the elevation ranging from 1800m to 4000m above the mean sea level (Shrestha et al., 2015; Gaire et al., 2019). Blue pine is sensitive to climate variability and researcher on dendrochronology have recommended for more study to be carried out on this species. Compared to other conifer species from the Himalaya region of Nepal Blue pine is fewer studies species (Gaire et al., 2013; Thapa et al., 2017). So the study of tree growth based on annual rings and its changing climate of this species will help decision-makers for managing the forest ecosystem well in the future.

Study area:

The study was carried out in Manaslu Conservation area, Nepal. As the protected areas are free from anthropogenic disturbances, the Manaslu Conservation Area (MCA) of the Gorkha district was selected as the study area. MCA has a fragile but diverse natural resource consisting of 11 different types of forest with conifers as the dominant species (NTNC, 2015; MCA, 2017). The map of the study area and the site selected is shown in figure 1.

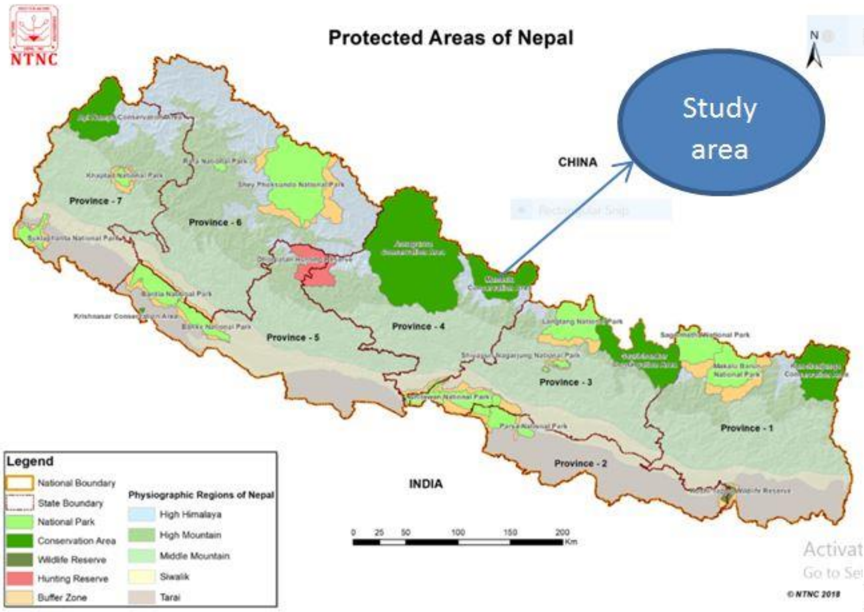

Fig 1. A map showing the Mansalu conservation area (MCA) of Nepal (Source: NTNC, 2018)

Field visit and data collection

Fieldwork was carried out from March to April 2017. Data were collected and processed by following dendrochronological methods adopted by Gaire et al., 2011, Kharal et al., 2016 and Aryal et al., 2018 for their research on the conifer of Himalaya of Nepal. Sweden made increment borers were used to extract the cores from the trees. A total of 70 cores were extracted from 35 trees of their breast height (1.3m). Extracted cores were then immediately kept in the plastic straw pipe with proper labeling. In addition, the altitude, latitude, and longitude were recorded by using GPS.

Laboratory procedure:

Sample preparation: Dendrology laboratory of Nepal Academy of Science and Technology (NAST) was used for further procedure. A standard dendrochronological procedure was applied for processing and analyzing. Collected cores were left for 10 days for air drying at room temperature. After that air-dried core was placed in grooved wooden mounts with a cross-section view facing up for 10 more days again. After that, cores were sanded by using sanding machine as well as manually by using various grits of sanding belts and papers (120 to 800) until the ring surface became distinctly visible under binocular microscope of LINTAB™.

Sample measurement: Age counting as done with the help of LINTAB and maximum age of the tree was found 119 years which is sufficient to establish tree ring chronology of Blue pine. Generally, the chronology is started above 50 years. Ring width of each core was measured to the nearest 0.01mm using a LINTAB™ consisting of an attached binocular microscope and a computer program called TSAP-Win (Rinn, 2016).

Cross dating: Cross dating of chronologies was used to remove false rings and identify missing rings so that annual rings are correctly dated. It was done by using TSAP-Win and the quality of dating was checked by software COFECHA (Holmes, 1983; Grissino-Mayer, 2001). The tree ring series were repeatedly checked by COFECHA. The cores which did not get cross dated were eliminated. The aim of cross-dating was also to assign accurate calendar dates to each annual ring of the core. A total of 31 series were chosen for chronology development.

Standardization and Chronology development

The corrected ring width data were standardized using computer software ARSTAN (Cook, 1985). The ring-width series were standardized using conventional detrending methods with appropriate options of a negative exponential, linear or cubic spline curve to each series. Each ring width index series was then pre whitened using autoregressive modeling to remove any autocorrelation effect (Cook, 1987) Finally, 4 different chronologies were developed namely raw chronologies (using cross dated ring-width data), standard chronologies (by detrending cross dated ring-width data), residual chronology (pre whitening the standardized ring-width indices) and the ARSTAN chronology (inbuilt one). Different Chronological statistics like mean sensitivity, standard deviation, auto-correlation, Signal to Noise Ratio (SNR), Expressed Population Signal (EPS) was also computed by ARSTAN through which decision on selection between the standard and residual chronology was made for the further analysis. Residual chronology was selected as the fit one for the study.

Tree growth-climate relationship

In this study, instrumental climatic data (temperature and precipitation) of the Gorkha Bazar meteorological station were taken to study the changes in climate. As the residual chronology was selected, its ring width index was then related to instrumental climatic data. Pearson correlation analysis was carried out between the residual ring-width index and mean temperature and precipitation of 33 years, on a seasonal basis to analyze tree growth-climate relationships.

Results

Chronology statistics: Total 31 well cross dated samples were analyzed using ARSTAN program and three different chronologies of a more than a century long dated from 1899 to 2017 were developed namely, raw chronology, standard chronology, and residual chronology. Raw chronology is based on the measurement of ring-width which is developed due to climatic and other non-climatic growth affecting factors and depicts the growth trend of Blue pine from 1899 to 2017. The maximum width of the ring was 6.84 mm in the year 1904 whereas the minimum was 0.94 mm seen in the year 1925. The mean ring-width growth for 119 years was 3.03 mm per year. The raw chronology width was compared with its 5-year moving mean, which clearly showed that ring-width growth was seen highest between 1899 and 1908; the growth rate then decreased sharply up to 1925. A higher growth rate was also seen between the year 1926 to 1945 and 1966 to 1987. After 1997 the growth rate showed a decreasing trend. The raw chronology was detrended using a negative exponential curve to reduce the noise (non- climate-related growth), which standardized the ring-width measurement into the ring-width indices to form a standard chronology. The chronology was further pre- whitened using an auto-regressive model to reduce the auto-correlation effect of the tree and form the residual chronology. Both the standard and residual chronology showed the growth trend of Blue pine from 1899-2017.

Standard vs residual chronologies

As the raw chronology consists of the age-related, climatic and other non-climatic growth signals, standard chronology, and residual chronology provide the best climate-related growth signals required for analyzing tree growth-climate relationships. Different chronologies statistics were calculated using ARSTAN program to make a decision on selection between standard and residual chronology. Computed statistics are shown in Table 1.

Table: 1. The chronology statistics of *Pinus wallichina* after standardization

Statistics	Standard Chronology	Residual Chronology
Chronology Time Span (AD)	119 years (1899-2017)	119 years (1899-2017)
Number of series (Trees)	31 (20)	31 (20)
Mean Sensitivity	0.234	0.284
Standard Deviation	0.383	0.416
Auto Correlation coefficient	0.619	0.064
Common Interval Time Span)	61 years (1957-2017)	61 years (1957-2017)
Number of series (Trees)	23 (15)	23 (15)
Mean- Correlation among all series	0.313	0.358
Mean - correlation within tree	0.521	0.490
Mean - correlation between tree	0.354	0.375
Effective Chronological Signal	0.354	0.355
Signal to noise ratio (SNR)	9.063	9.908
Expressed Population Signal (EPS)	0.901	0.889

Both the chronologies are 119 years long built using 31 cross dated cores from 20 trees. The common interval time span for both chronologies was 61 years (1957-2017) covered by 23 cores from 15 trees, where the largest possible number of tree-rings analyzed falls under. Comparing the chronologies from 1899 to 2017, the residual chronology has high mean sensitivity, a higher standard deviation and also autocorrelation effect has been removed by AR modeling (Table 1), so it was selected for the tree growth and climatic variables response.

Climatic data

The precipitation and temperature data of the Gorkha Bazar metrological station (Table 2) was taken for climatic analysis. Due to the limitation of long instrumental data we analyzed 33 years (1985 to 2017) instrumental climatic data. The details of the climatic variables and their values are given below in Table 2.

Table: 2. Climatic data of the Gorkha bazar meteorological station from 1985 to 2017

Climate variables	Values
Mean precipitation & Mean temperature	138.6 & 21^0C.
Highest precipitation (1995) & Lowest precipitation (1998)	193.8 & 60.7
Precipitation trend & R^2 value on precipitation trend	-0.2599 & 0.0071
Mean annual maximum temperature & R^2 value on mean annual maximum temperature	26.9^0C &0.7036
Mean annual minimum temperature & R^2 value of mean annual minimum temperature	16.1^0C & 0.0993
Mean annual temperature trend & R^2 value on mean annual temperature trend	0.0659^0C/year & 0.457

Climatic response of Blue pine on a seasonal basis

Pearson correlation was carried out between the residual ring-width chronology and total precipitation and mean temperature of 33 (1985 to 2017) years on seasonal basis. The analysis showed that the seasonal precipitation, the tree ring width correlated negatively with the post-monsoon but positively with other seasons rainfall (Fig. 2). Similarly, the tree growth negatively correlated with all the mean seasonal temperatures and correlation was significantly negative with the pre-monsoon ($r = -0.378$, $p < 0.05$) (Fig. 2). Because of low pre-monsoon precipitation and high pre-monsoon temperature. Pre-monsoon season creates the water-stressed condition affecting the tree-ring growth.

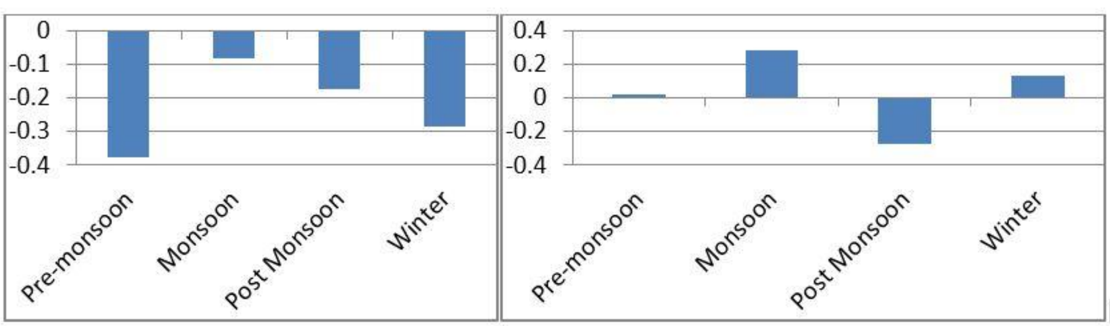

Fig. 2. Tree ring growth response to seasonal temperature and seasonal precipitation (1985 - 2017)

Discussions

Tree-Ring Chronology

Three different chronologies namely raw chronology, standard and residual chronology were built from the tree-ring series developed from the cross dated samples using ARSTAN program (Cook, 1985). All the chronology showed the growth trend of Blue pine for the past 119 years ranging from 1899 to 2017 with the common time interval of 61 years (1957 to 2017) covered by 23 cores from 15 samples, where the largest possible number of the tree- rings analyzed falls under. The raw chronology is based on the ring width measurement and depicts the growth of Blue pine in the natural condition which is affected by both the climatic and non-climatic factors. The mean annual growth rate shown by the raw chronology was 3.03 mm per year and the highest growth rate was seen between the years 1899 and 1908 and the decreasing trend of growth after 1997.

In order to study the response of the tree to climate variability, it is required to capture only the climatic signals in the chronology. Hence the raw chronology was detrended using a negative exponential curve to reduce the noise i.e non-climate-related growth or age-related growth. According to Speer (2010), negative exponential curve generally follows the model of tree growth, particularly of the pine forest showing decreasing thickness of rings from pith to bark, grown in an open area and not experiencing any kind of disturbances and many researchers has used this detrending method for both the *Pinus roxburghi* and Blue pine as well (Asad et al., 2017; Asad et al., 2018; Aryal et al., 2018; Sigdel et al., 2018). The standard chronology so detrended was then whitened using autoregressive modeling to remove the autocorrelation effect of the tree and enhance the common signals i.e. climatic signals (Cook, 1985) and residual chronology were formed. The selection between the standard chronology and residual chronology to study the response was based on the statistics so computed. In order to study the tree-growth response, chronologies with higher mean sensitivity, higher standard deviation, and lower autocorrelation coefficient are required (Fritts, 1976) and based on this residual chronology was selected for the study. The chronology of Blue pine built in this study was of 119 (1899 to 2017) years from Gorkha, whereas another researcher like Schmidt et al. (1999) developed the first master chronology for Nepal covering the time span ranging from 1324 to 1997, including Blue pine, from different area of Mustang, Manang, and Khumbu. The longest chronology for Blue pine developed so far is of 694 years (1303-1996) from the archeological wood from Bhratang (Cook et al., 2003). The peak points and lower points in the residual chronology show the higher and lower ring-width indices representing higher growth and lower growth at respective year.

Climate Change Impact on Blue pine

The pre-monsoon season was seen as the most drought stress condition for the radial growth of the Blue pine show a slight increase or decrease in the mean annual temperature and the precipitation can have great influence in its growth. So, the trend of the pre-monsoon season of the last 33 years was analyzed with temperature which showed a significant correlation with the temperature and the precipitation as well. The trend of climate showed that the precipitation was decreasing at the rate of -1.8905 mm per year (R^2= 0.0164) while the temperature was increasing by 0.0814 ^oC per year (R^2= 0.293). This pattern shows the more drought-stressed condition and hence affecting the radial growth of the tree. The precipitation of the pre-monsoon was positively correlated and temperature is negatively correlated with tree growth. So; the impact of climate change on the Blue pine forest can be seen as the warming of the pre-monsoon negatively affecting the radial growth of the plant. Decreasing trends in winter and pre-monsoon precipitation are being observed, with increasing drought and rising temperatures in recent decades across western and northwestern Nepal (Sigdel & Ikeda., 2010; Wang et al., 2013). Under severe drought conditions, high competition for moisture between neighboring trees will further exacerbate drought stress for tree growth (Liang et al., 2016; Gleason et al., 2017). Ongoing warming temperatures could not only cause soil moisture deficiency but also amplify temperature-induced drought stress, thereby limiting tree growth and posing a risk of dying under a warming climate (Allen et al., 2010; Camarero et al., 2015).

Conclusions:

The study was carried out in the Manaslu conservation area lying at an altitude between 2500 to 3000 m. Samples from the lower altitude consisted of more false rings. Despite the difficulties, a century-long (119 years) chronology dating back from 1899 to 2017 was constructed, which shows the growth pattern of the Blue pine for the past century in the study area. The chronology of the studied species showed a negative correlation to the temperature of the pre-monsoon. Analyzing the mean monthly temperature and precipitation trend of 33 years (1985-2017), a rapid increase in temperature and low rainfall during the pre-monsoon creates the water-stressed drought condition affecting the tree-ring growth. Moreover, the mean annual climatic trend for the pre-monsoon showed a rise in temperature and a decrease in precipitation leading to the drought condition. According to these findings, the precipitation during the pre-monsoon was found as the major growth-limiting factor of the Blue pine. This study has analyzed the data towards the growth response of Blue Pine which could be reference for the conservation and management of the Himalayan ecosystem.

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Conflict of Interest

The author declares no conflict of interest

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