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Growth Response of *Pinus wallichiana* to Changing Climate in Temperate Regions of Central Nepal

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Abstract

Climate influences both the structure and function of the forest ecosystem. A dendrochronological study was carried out in temperate forest at Patney Bhanjyang Community Forest of Kavrepalanchok district in Central Nepal to verify and record the impact of climate on radial growth by using the tree cores of *Pinus wallichiana*. A total of 60 tree cores were collected by using increment borer and annual ring widths were analyzed by using the standard dendrochronological technique. We produced a 74-year-old tree ring width chronology of *P. wallichiana* from the region and examined the critical climatic factor for radial growth and the temporal trend of Basal Area Increment (BAI). Our results showed that the tree radial growth was not influenced by maximum temperature. However, it was positively correlated with the minimum temperature of the previous year September (0.30) indicating that cool previous September is favorable for radial growth. Similarly, the radial growth of Pine showed a positive correlation with the total rainfall of January (0.33) and March (0.33), showing that enough moisture in the very early growing season contributes positively to radial growth. We found a decline in BAI after 2000 AD until 2005, although BAI was relatively stable despite the decreasing trend of rainfall. We did not find the impact of climatic factor for the decline in BAI. However long-term study of different climatic, ecological and anthropogenic influences are necessary to know more about the growth–climate relationship of *P. wallichiana* in temperate forests of Nepal.

Keywords: Basal Area Increment (BAI), *Pinus wallichiana*, Radial growth, Tree-rings

Introduction

Various evidence indicate that the continuous increase in temperature in recent future is certain and the future trend of precipitation pattern is uncertain (Intergovernmental Panel on Climate Change [IPCC], 2014). The global climate has never been static and has shown great variability since its origin. The recent change, however, is accelerated by the greenhouse effect causing abrupt temperature to rise and unpredictable patterns of precipitation (Houghton, 2004). The repository of biodiversity, Mountain is the home to many endangered species. In the mountain area, with the increase in elevation over short horizontal distances, much vegetation are changing, so these area are the unique place to detect climate change and assessment of climate related impacts (Whinteman, 2000). In general, the temperature is the influencing predictor variable of tree line formation and maintenance as well as species line deformation (Harsch et al., 2009). The impact of climate change has been seen on species distribution, population structure, vegetation shifts, vegetation composition, phenology and growing season in global scale (Carrer et al., 2016; Gaire et al., 2017; Theurillat & Guisan, 2001; Ziaco et al., 2014). The widely observed phenomenon, global warming is the main cause of shifting of the plant species into higher elevations which has led to an entire increase in the number of species on mountain summits (Grace et al., 2002).

Nepal, a Himalayan country, is highly threatened by the impact of climate change. The atmospheric temperature in Nepal has been increasing at a rate of 0.04 to 0.06ºC per year, with a higher rate than global average (Shrestha & Aryal, 2011; Shrestha et al., 1999). Nepal is more prone to climate change due to the fact of the higher rate of warming in higher altitude. Due to absence of long term instrumental climatic data, it has become a major problem of studying climate change in Nepal (Cook et al., 2003). By using several alternatives, past climate could be estimated. One of such alternatives is dendrochronology and dendroclimatology (Chhetri & Thapa, 2010; Cook & Kairiukstis, 1990; Fritts, 1976; Gaire et al., 2013; Speer, 2010; Thapa et al., 2014). In fact, dendrochronology can date the time at which tree rings were formed, in many types of wood, to an exact calendar year (Speer, 2010). Dendrochronology and its sub disciplines such as dendroclimatology use tree rings as a proxy because tree rings are an exceptionally a biological recorder and databank that stores valuable source of paleoclimatic information from the environment which can be used to reconstruct the yearly variation in climate that occurred prior to the interval covered by direct climatic measurement. The species of temperate genera *Abies spectabilis* (Fir), *Betula utilis* (Birch), *Juniperu* spp. (Juniper), *Pinus* sp. (Pine), *Larix* sp. (Larch) etc. have already been proven to have great dendrochronological potential (Gaire et al., 2013). In context of Nepal, dendrochronological studies have been carried out on more than 20 species consisting of conifers like *Abies spectabilis*, *A. pindrow*, *Cedrus deodara, Jniperus indica*, *J. recurva*, *Larix potaninni*, *L. griffithiana*, *Picea smithiana*, *Pinus roxburghii*, *P. wallichiana* and *Tsuga dumosa* as well as broad leaved species like *Acer* sp., *Alnus nepalensis*, *Betula utilis*, *Castanopsis indica*, *Hippophae salicifolia*, *H. tibetana*, *Neolitsea palens*, *Rhododendron campanulatum*, *R. arboreum, Schima wallichi*, *Sorbus* sp. and *Ulmus wallichiana*. There are several other trees and shrub species which have been included in the potential species list for dendroclimatic study (Gaire et al., 2013). Tree ring studies in Nepal Himalaya region have been restricted to the high mountain forests including subalpine forest and treelines however, few studies are carried out at subtropical region and temperate regions (Speer, 2010). Hence, we wanted to analyze the growth-climate response of *P. wallichiana* forests in the lower temperate forests of Central Nepal; which represents the substantial forest area and is well exposed to rapidly changing climate.

Materials and Methods

Study area

The study was conducted in the Patney Bhanjyang community forest of Bethanchok Rural Municipality, Kavrepalanchok. This community forest was established in 2053 BS which occupies an area of 376.76 ha. The Patney Bhanjyang forest is sub-tropical and temperate mixed evergreen forest extending from 1400 to 2780 m elevation associated with temperate climate. It has a great diversity of forests. The higher part of Patney Bhanjyang forest is dominantly covered by *Pinus wallichiana*, *Rhododendron* spp. and *Quercus* spp., and the lower part is dominantly covered by *Alnus nepalensis*, *Schima wallichii* and *Juglans regia* (field observation).

The Patney Bhanjyang Community Forest (Figure 1) is the nearest natural coniferous forest of Bethanchok which intensively provides varieties of ecosystem to over 300 households and surrounding Community Forests User Groups (CFUGs). This region is less explored in terms of the scientific research regarding the impact of rapidly changing climate to local forest so, people are unaware about the growth pattern of forest. With a growing population and increasing demand for forest products and land, forests can be expected to be under increasing pressure again. This could affect the livelihood of a large number of people. According to the information provided by CFUGs, this forest provides Non-Timber Forest Products (NTFPs) in a large scale to the local people. Local people collect the *Juglans regia, Valeriana jatamansi, Asparagus* spp., *Urtica dioica, Artemisia* spp*., Paris polyphylla* for the local use as a medicine. As being natural community forest, people collect timber, wood, fodder etc. but commercially forest products are not extracted.

Species

Pinus walliciana is a coniferous evergreen tree native to Hindu Kush Mountain. It grows in mountain valleys at altitude of 1800-3300 m (rarely as low as 1200 m), between 30 m and 50 m in height. Sometimes it forms pure stands of forest,

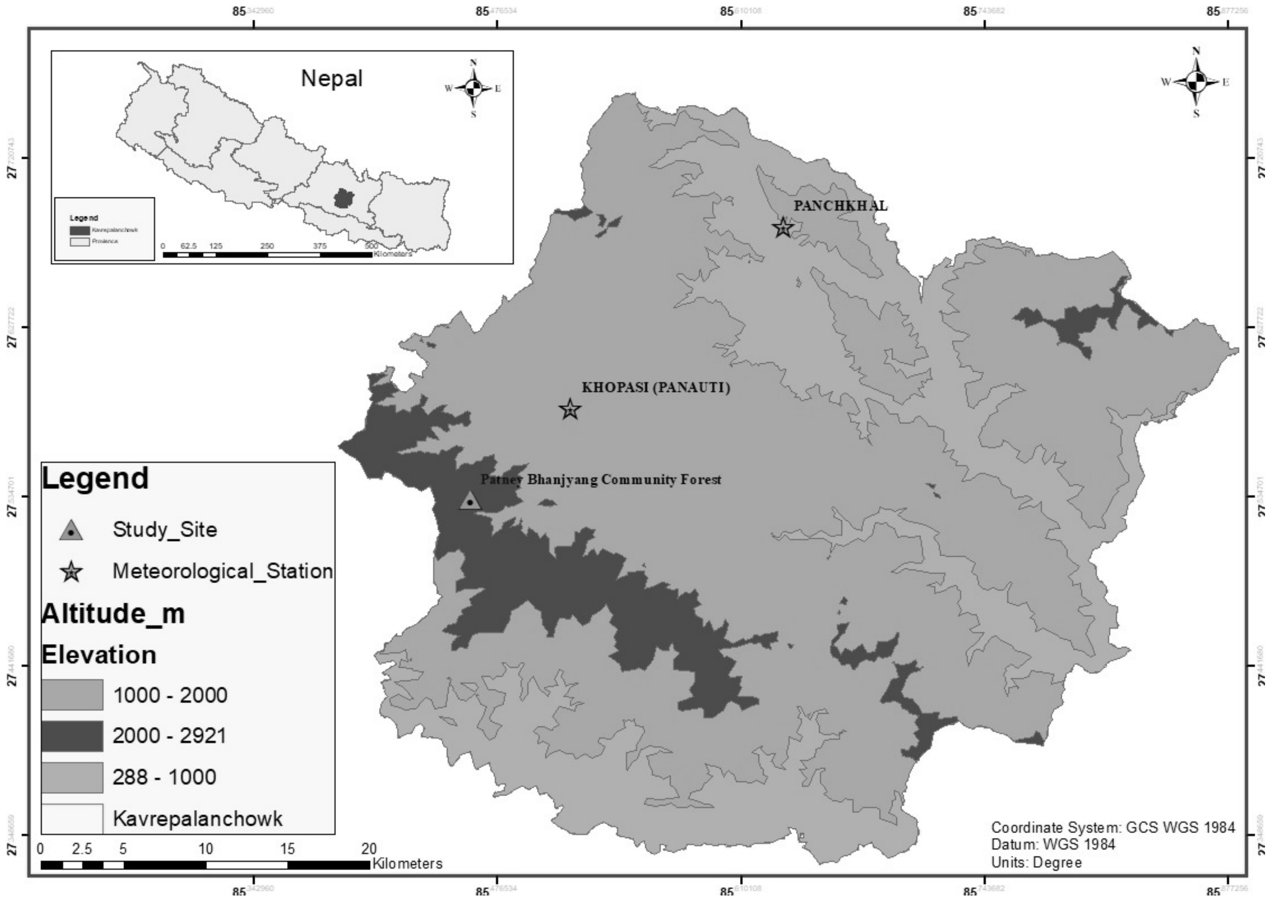

Figure 1: Map of study area, Patney Bhanjyang, Bethanchok, Kavrepalanchok

in other places it appears as an important forest component mixed with broad-leaved trees such as species of the genera *Quercus*, *Acer, Ilex* and *Betula* (The Gymnosperm Database, 2009). In the western Himalayas, where the conditions are drier, it forms mixed forest with *Cedrus deodara*. Other conifers with which it may be associated are *Pinus roxburghii*, *Abies spectabilis*, *A. densa* and *Tsuga dumosa* in the wetter eastern part of its range (Stainton, 1972). *Pinus wallichiana* favors a temperate climate with dry winters and wet summer. In some places it covers the range up to treeline. Much past evidence shown that this species has the great multiple aspects of dendrochronological studies (Bhattacharyya et al., 1992) because of its clear annual rings and wide geographical coverage. *P. wallichiana* is one of the most important tree species for the local people since it offers timber, resins, wood. In Kavrepalanchwok, at higher elevation, the forest was exclusively dominated by *P. wallichiana* with evergreen oak forest which is suitable for our study.

Sample collection and measurement

In total, 30 healthy and matured trees were selected and diameter at breast height (i.e., 1.3 m above ground level) was measured. A total of 60 cores were taken from 30 trees. One to three cores per tree were cored at breast height, using Increment borer. The extracted cores were collected in the core holder straw. The cores were air dried for a few days and analyzed at dendrochronology lab of Forest Research and Training Center (FRTC) of Ministry of Forests and Environment, Babarmahal, Kathmandu. After the samples were dried, the cores were then smoothened manually with sanding paper of grids ranging from 120-800 to make the annual rings visible. The cores with visible annual rings were dated to the calendar year. Every single ring in each series was counted from bark to pith under the stereomicroscope adjusting the resolution for clear visualization. The tree- ring measurement was done using a hardware called LINTAB which is connected with a computer program TSAP (Rinn, 2003). Ring width was measured at a resolution of 0.001mm (Speer, 2010) precision using LINTAB.

The individual tree ring series were cross dated using alignment technique, looking the math graph and cross dating statistics as explained by (Rinn, 2003). After the complete ring-width measurement, each dated ring was taken for the error check. The error in the cross dating was rechecked and confirmed by using the computer program COFECHA developed by Richard Holmes (Holmes, 1983). A computer program ARSTAN was used to carry out standardization (Cook, 1985). The detendring of each sample was done using negative exponential curve to estimate the ring width in order to reveal the non-climatic age trends, i.e. low frequency variance (Cook & Peters, 1981).

Climatic data

The climatic data were collected from the nearest climate station. The temperature and rainfall data of Panchkhal and Khopasi were taken from the Department of Hydrology and Meteorology (DHM), Kathmandu. The meteorological data indicated that the mean maximum temperature in the Panchkhal area is 32.50ºC and the mean minimum temperature is 4.56ºC (Figure 2). The highest rainfall occurred in the month of July. The gradual increase in rainfall and temperature was from May to July and it declined from August to December.

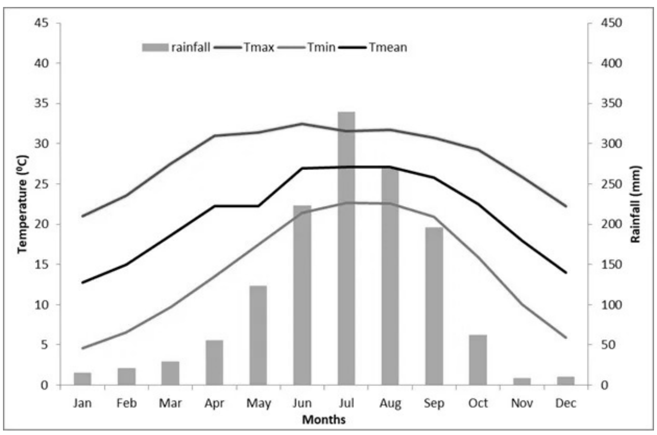

Figure 2: Monthly patterns of average temperature and monthly total rainfall

Growth-climate response

After the process of standardization and mean chronology development, the residual tree ring chronology of *Pinus wallichiana* of Patney Bhanjyang forest was related with the instrumental climatic data recorded from Panchkhal and Khopasi meteorological station. The correlation and response analysis process were done by using the MS-Excel. The correlation and response between tree ring chronology and monthly average temperature and rainfall was done from the month of January of the previous year to December of the current year. The seasonal response was analyzed forming four seasons. Pre-monsoon (March, April, May), Monsoon (Jun, July, August, September), Post-monsoon (October and November) and winter (January, February, December). Linear correlation coefficient was used as the indication of the extent of the relationship between climate and chronology.

Results and Discussion

Climatic trend

There is an increasing trend of annual average maximum temperature at the rate of 0.03670°C/yr (R^2=0.50). The mean temperature also showed be increasing trend at the rate of 0.01670°C/yr although it is not a significant trend. However, there was not a significant trend in rainfall patterns for the last four decades (Figure 3). This pattern shows that the rainfall trend is stable, and the maximum temperature is constantly increasing, this may cause water stress condition and thereby radial growth of the tree. In a 74-year tree ring width chronology there was a fluctuating trend in a different year. In the year 2006, there was maximum growth whereas, in 2000 AD, it reached a minimum value. When drought and temperatures are increasing in recent decades across western and northwestern Nepal (Sigdel & Ikeda, 2010; Wang et al., 2013), there is decreasing trend in winter and pre-monsoon precipitation. Under severe drought conditions, high competition for moisture between neighboring trees will further exacerbate drought stress for tree growth (Gleason et al., 2017; Liang et al., 2016). 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 of trees under a warming climate (Allen et al., 2010; Camarero et al., 2015).

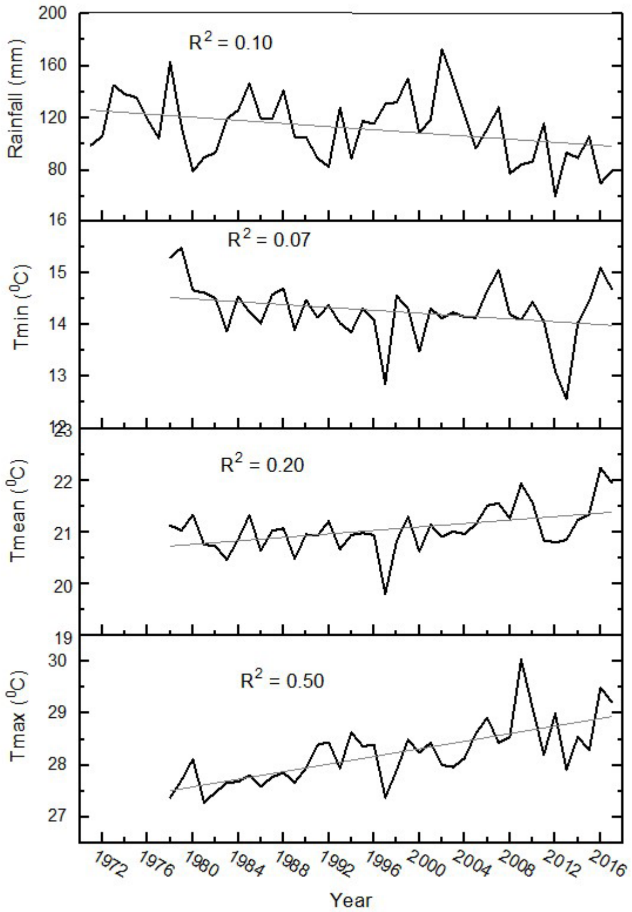

Figure 3: Trend of annual temperature and rainfall in the study site

Tree-ring chronology

We produced a 74-year tree ring width chronology from 60 tree cores (30 trees) of *P. wallichiana* population from Bethanchok (Kavre) in central Nepa (Figure 4). The chronology has fulfilled all the statistical parameters used in standard dendrochronological studies. The tree ring width chronology of *P. wallichiana* is showed standard chronology (using ARSTAN), and the ring width indices showed fluctuating trend in a different year. The maximum growth was observed in 2006 AD and it was minimum in 2000 AD.

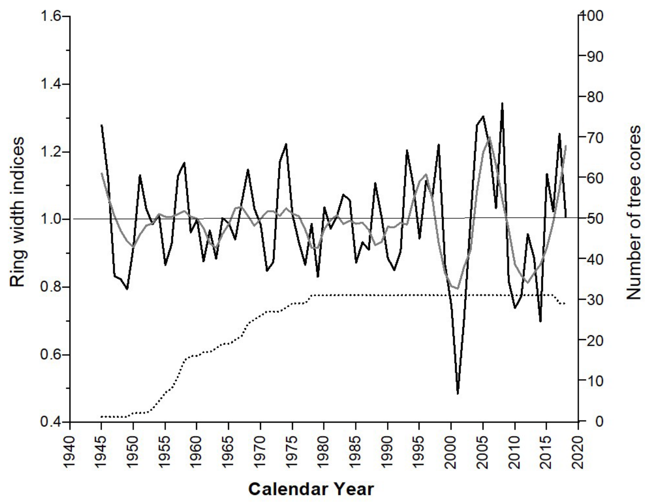

Figure 4: Tree ring-width chronology of *Pinus wallichiana*; which showed standard chronology of ring width indices (using ARSTAN), the dotted lines represent the number of tree cores, and the grey line is the smoothing line for 5 years window

Growth-climate relationship

The growth climate relationship indicated that the tree radial growth is not influenced by Tmax, although Tmax is significantly increasing in the region over time. The radial growth was positively correlated with minimum temperature (Tmin) of previous year September ($r = 0.30$, $p < 0.05$). It indicated that the cool climate in previous September is favorable for radial growth. The correlation between radial growth and minimum temperature during growing season (July; $r = 0.42$, $p < 0.05$), and late growing season (November; $r = 0.21$, $p < 0.05$) was also reported in previous studies (Gaire, 2008).

Table 1: Chronology statistics

Chronology Length	Mean Ring Width Index	Standard Deviation	Inter-series Correlation	EPS (2000)
74 Years (1945-2018)	0.989	0.156	0.426	0.909

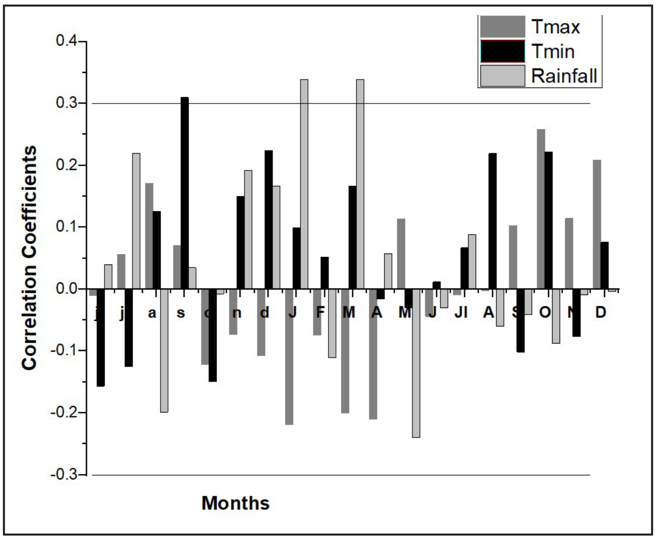

Figure 5: Correlation coefficients between radial growth and total monthly temperature (Tmax, Tmin) and rainfall

In the western Himalaya (Northern Pakistan) the radial growth of *P. wallichiana* showed significant positive correlation with winter (December-January) temperature and showed no significant correlation with precipitation (Fayaz et al., 2018). However, our study showed that the radial growth of *P. wallichiana* is positively correlated with total rainfall of January ($r = 0.33$, $p < 0.05$) and March (0.33, $p < 0.05$), this showed that the more moisture in very early growing season contributes positively to radial growth. Many studies in Nepal Himalaya showed spring season moisture influence on tree radial growth (Aryal et al.,2018; Dawadi et al., 2013; Tiwari et al., 2017). Similar studies from central Nepal (Panchase) showed a significant positive relationship between spring season (March, April) rainfall and radial growth (Aryal et al., 2018) indicating that the climatic response to radial growth is also site specific. The studies carried out by Shah et al. (2009) regarding the climatic influence on radial growth of *P. wallichiana*in India, showed that the pre-monsoon precipitation (December-April) is a significant factor for influencing the radial growth. Overall, we observed that more rain during winter season is good for radial growth of *P. wallichiana*, however the very dry spring season (March-May) will have a negative influence on the radial growth.

Basal Area Increment (BAI)

Generally, age-related trends of BAI in mature forest stands are positive. BAI may continue to increase in healthy stands (Duchesne et al., 2003; LeBlanc 1992), or stabilize (LeBlanc et al., 1992), but it doesn't show a decreasing trend until trees begin to senesce or unless trees are subject to significant growth stress (Duchesne et al., 2003; Jump et al., 2006; Weiner & Thomas 2001).

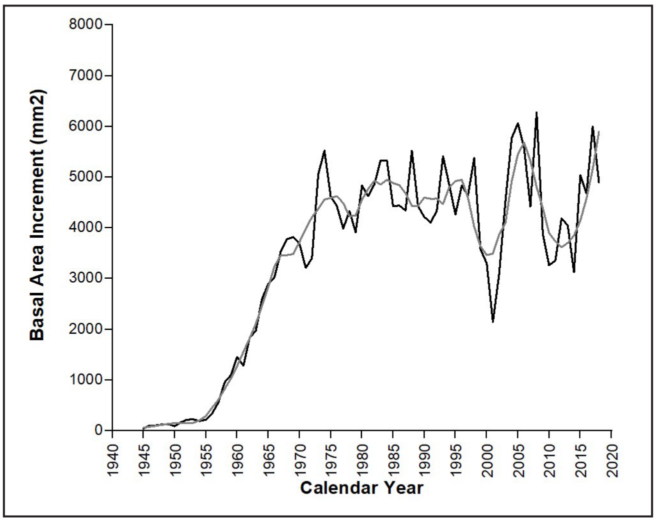

Figure 6: BAI through time; the smoothing grey line operated for five years period

Our results showed that there was a decline in BAI during 2000-2005 AD, and it could be explained by climatic factors in the study area. The decline in BAI could be the influence of forest fire, thinning, timber collection (field observation). Climate induced growth decline was already evidenced for drier parts of the Trans-Himalayan zone of Nepal, where tree growth was found to be positively correlated with spring season rainfall (March- May) and negatively correlated with maximum temperature (Tmax) during spring season (Tiwari et al., 2017). The BAI pattern appeared a little abnormal irrespective of the juvenile growth trend, although the overall BAI trend in the study area showed the normal tree growth pattern and *P. wallichiana* is still vigorous in terms of growth characters.

Conclusion

We have reconstructed a 74-year long tree ring-width chronology of *Pinus wallichiana* from Patney

Bhanjyang community forest, Bethanchok in the temperate region of central Nepal. The ring width indices showed a statistically significant positive correlation with the minimum temperature of previous year September and a positive correlation with total rainfall of January and March of current growth year, showing that the moisture availability of early growing season is critical for radial growth of *P. wallichiana.* The BAI trend showed no significant trend in BAI pattern; it showed normal sigmoidal pattern (increasing BAI) as of healthy forests. However, there was a decline in BAI after 2000 until 2005 AD. This decline was not found to be correlated with climatic factors but could be due to the influence of local stand level disturbances such as forest fire, grazing and lopping and timber collection from the forests. We emphasize that both stand level (local) as well as regional ecological factors should be analyzed for describing growth–climate relationship of *P. wallichiana* from the temperate region mid hills of Nepal.

Author Contributions

AT conceptualized and designed the research, TS and NT collected samples, and performed the laboratory measurement. AT, SB performed data analysis. The authors read and approved the final manuscript.

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