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Growth response of seven multipurpose tree species to climatic factors: A case study from northwestern Himalayas, India

Sucharita Panda, D.R. Bhardwaj, C.L. Thakur, Prashant Sharma, Dhirender Kumar*

Department of Silviculture and Agroforestry, Dr YSP University of Horticulture and Forestry, Solan, India

**Corresponding author: prashantsharma92749@gmail.com*

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Abstract: Identification of the species for dendrochronological studies is of great relevance to understand various aspects of climate change. However, in the northwestern Himalayan region, dendroclimatological investigations are confined to conifer species, with broadleaved species being disregarded. Thus, the present study was conducted to assess the growth response of seven multipurpose tree species (MPTs), namely *Bauhinia variegata*, *Celtis australis*, *Grewia optiva*, *Paulownia fortunei*, *Toona ciliata*, *Ulmus villosa* and *Melia composita* to local climate variables, viz. temperature as well as rainfall (seasonal, monthly, average) and CO_2 level by evaluating the climatic signal in tree ring chronologies at Solan district, India (altitude 1 250 m) in the mid-hills of the northwestern Himalayas. The results indicated that only the maximum, rainy season temperature and CO_2 level varied significantly ($P < 0.05$) between 1991 and 2017. Only *G. optiva* exhibited a significant ($P < 0.05$) tendency toward increased growth. *C. australis* has a remarkable negative correlation with temperature variables, viz. average, maximum, spring season, March temperature, whereas *T. ciliata* exhibits a positive correlation with temperature variables, such as rainy season, average and April temperature. Similarly, winter, total and December rainfall have a profound effect on *P. fortunei*, while March rainfall adversely affected the growth of *B. variegata*. On the other hand, *G. optiva* demonstrated sensitivity to both temperature (February and May) and rainfall variables (winter, February and May). *U. villosa* recorded a positive correlation with rainfall (autumn and October rainfall) but a negative correlation with temperature variables (maximum and April temperature). Elevated CO_2 levels affected only two species (*G. optiva*, *M. composita*) out of the seven selected species. Our findings will contribute to a better understanding of the climate growth relationships of investigated tree species, as a result, to more accurate projections of the effects of climate change on these MPTs and directing future studies.

Keywords: broadleaved tree species; CO_2 level; dendrochronology; rainfall; temperature

Multipurpose tree species (MPTs) have an immense place in the rural economy (Tewari 1995) by providing versatile products both economically (fuel, fodder, fruits, fibres, timber and medicine) and ecologically (nitrogen fixation, environment and soil amelioration) (Nair 1993; Sharma et al. 2017b) including water protection, carbon sequestration (Verma et al. 2021), and ability to reclaim the degraded soil as well as wasteland (Sharma et al. 2017a). Inherently, MPT growth varies considerably from year to year, resulting in variation in the width of the annual growth rings that formed throughout every growing season (Jump et al. 2006). These deviations in annual rings of individual trees may be due to their physiology and wood anatomy or external influences, such as prevailing

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environmental conditions, which are also considered as decisive factors in tree growth (Bauwe et al. 2015). Tree growth has been known to be sensitive to rainfall (Grogan, Schulze 2012; Bauwe et al. 2015; Natalini et al. 2015), air temperature (Schweingruber 1996; Jump et al. 2006; Savva et al. 2006; Natalini et al. 2015), wind (Urban et al. 1994), solar cycles (Rigozo et al. 2002; Šimůnek et al. 2020) and air pollution (Putalová et al. 2019; Mikulenka et al. 2020; Sidor et al. 2021). Similarly, the radial growth of trees could also be affected by biotic factors, such as game damage (Cukor et al. 2019; Vacek et al. 2020), silvicultural treatments (Pérez-de-Lis et al. 2011; Remeš et al. 2015; Jaouadi et al. 2018) or fertilization (Ponton et al. 2019; Vacek et al. 2019; Gallo et al. 2021). However, these variables impact species differently and the same species at different habitat (Dié et al. 2015) depending on their environment.

Since the last century, the dendrochronology has been gaining importance. Over the decades, climate research have relied heavily on dendrochronological, i.e. tree ring data (Bauwe et al. 2015), since annual tree ring data serve as a valuable and indirect source of information about climate change and response (Fritts 1976). Moreover, knowing how trees develop in response to climatic variability is crucial for forecasting how various species will respond to climate change (Grogan, Schulze 2012; Jiao et al. 2019; Hájek et al. 2021). As stated in 2019 Special Report on climate change and land of the Intergovernmental Panel on Climate Change (IPCC), the mean air temperature already increased by 1.53 °C, and there was an increase in rainfall intensity, flooding and drought frequency, wildfire incidence and pest outbreaks compared to the pre-industrial period (before 1850). Even the northwestern Himalayas are not immune to the effects of the global climate change, as evidenced by 0.16 °C decadal temperature increase over the last century in conjunction with a declining trend in monsoon and annual average rainfall (Bhutiyani et al. 2007). Moreover, recent climate warming has lengthened the growing season for a number of species, especially in the northwestern Himalayas (Panda et al. 2021).

The identification of species for dendrochronology is critical for studying the numerous aspects of climate changes (Bhattacharya et al. 1992), along with species climate sensitivity, good crossdating and widespread geographical distribution. The species of the Himalayan region provide enormous possibilities for dendrochronological studies because the Himalayan ecosystem is one of the most impacted by climate change and its adverse effects (Gautam et al. 2020). Simultaneously, there is a dearth of literature on dendrochronological studies of broadleaved tree species in the northwestern Himalayas. Moreover, almost all the studies were concentrated during the 1979–1992 period and focused on the Himalayan evergreen conifer species like *Abies pindrow*, *Picea smithiana*, *Pinus roxburghii* and *Cedrus deodara* (Bhattacharyya et al. 1992).

Taking these factors into consideration, we examined the growth response of seven MPTs, viz. *Bauhinia variegata*, *Celtis australis*, *Grewia optiva*, *Paulownia fortunei*, *Toona ciliata*, *Ulmus villosa* and *Melia composita* to the climate change in the northwestern Himalayas by evaluating the climatic signal in tree ring chronologies. The objective of our study was to test the hypothesis that during the period 1991–2017 changing climate variables (temperature, rainfall and CO_2 level) had an effect on the growth of selected MPTs. So, it is conceivable to quantify the possibilities and potential ecological concerns linked with climate change for these seven MPTs.

MATERIAL AND METHODS

Site characteristics. The study was conducted at Solan, Himachal Pradesh, which is located in the mid-hill zone of the northwestern Himalayas (30°51'36''N, 77°10'23''E) at an elevation of 1 250 m a.s.l. (Figure 1). The area has a well-drained silty loam soil and subtropical monsoon with mild and dry winter, hot to moderately hot summer (Cwa and Cwb according to Köppen) with significant temperature variation (IMD 2010). May and June are the warmest months (29–31 °C), while December and January are the coldest months (up to 2 °C) with average annual temperature of 18.59 °C. The mean annual rainfall is around 1 150 mm, with most of the rain falling during the months of July and August (more than 40%) while October (25.4 mm), November (6.89 mm) and December (21.79 mm) are the driest months (Panda et al. 2021).

Sampling and observation. We selected seven species, namely *Bauhinia variegata*, *Celtis australis*, *Grewia optiva*, *Paulownia fortunei*, *Toona ciliata*, *Ulmus villosa* and *Melia composita* based on the utility to the local people, feasibility of getting adequate samples and visibility of growth rings

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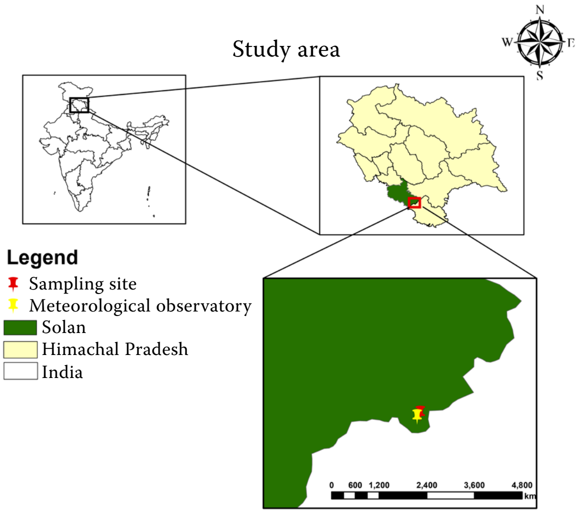

Figure 1. Map of study area showing sampling site

for each species (Table 1). The seven species chosen represent the region's key MPTs and are favoured by locals over other species for afforestation and reforestation efforts owing to their ability to provide diversified products. The individuals for different MPTs were selected randomly and all the selected trees were distinct solitary individuals which were left to spontaneous development in the study site. Three full stem discs of each species were obtained at breast height because Brienen and Zuidema (2005) suggested that it is necessary to collect full stem discs when working with new species to ensure dating accuracy and growth pattern analysis. In the laboratory, discs were air-dried, sanded using progressively finer sandpaper until cells were clearly visible, then polished to enhance the clarity of ring boundaries. To account for the uneven form of the disc tree ring widths were measured and averaged over the four radii per disc perpendicular to each other. All tree ring boundaries were marked with pencil prior to measurement, and the middle of the pith was used as beginning point for each radius. Each radius of the samples was visually crossdated twice using the Labline Binocular Prime Microscope (Labline Stock Centre, India) to exclude miscounting or false ring counting, using the methodology of Yamaguchi (1991). The standardization procedure followed Fritts (1976) approach for determining the relative tree ring index [Equation (1)].

Table 1. List of the multipurpose tree species analysed with leaf fall behaviour and products

Botanical name	Common name	Family	Average tree height (m)	DBH (cm)	Age (years)	Adult stature	Leaf fall behaviour	Products
Bauhinia variegata L.	mountain ebony	*Fabaceae*	10–12	12–21	17–29	canopy	deciduous	food, fodder, fibres, fuelwood, tannins
Celtis australis L.	European nettle tree	*Cannabaceae*	20–25	17–37	20–37	emergent	deciduous	vermifuge, fodder, fibre, timber,
Grewia optiva Drumm.Ex Burret	bhimal	*Malvaceae*	13–15	35–40	57–62	canopy	deciduous	fodder, fibres, fuelwood, indigenous cosmetics
Melia composita Willd.	hill neem	*Meliaceae*	18–20	18–26	9–12	canopy	deciduous	timber, insecticidal (seed) and medicinal properties
Paulownia fortunei (Seem.) Hemsl.	dragon tree	*Scrophulariaceae*	25–28	19–37	10–19	emergent	deciduous/ evergreen	phyto-remediation, lumber, charcoal making
Toona ciliata M. Roem.	red cedar	*Meliaceae*	30–35	26–45	18–38	emergent	deciduous	timber, fodder, tannin and medicinal properties
Ulmus villosa Brandis ex Gamble	cherry bark elm	*Ulmaceae*	24–25	21–26	23–27	emergent	deciduous	fuelwood, fodder, timber

DBH – diameter at breast height

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$$I_t = \frac{R_t}{G_t} \quad (1)$$

where:

I_t – relative tree ring index;

R_t – actual ring width;

G_t – predicted ring width.

Thus, non-climatic age trends may be eliminated from the ring-width series, and the maximum standard signal can be obtained prior to averaging into mean chronology.

To gain a better understanding of the effect of climate change on tree growth and to establish a relationship, climate data, viz. temperature and rainfall, were obtained from the adjacent (less than 1 km) meteorological observatory of the College of Forestry, Dr YS Parmar UHF, Nauni Solan, India (30°51'26''N, 77°10'14''E; 1 254 m a.s.l.); while CO_2 data was obtained from the NASA website (https://data.giss.nasa.gov/modelforce/ghgases/). However, climate data was available only from 1991 to 2017, which was sufficient for six species, except *G. optiva*, which was 58 years old and for which only 1991–2017 climate data and ring width were taken for the analysis.

Statistical analysis. The data collected on the ring widths of seven distinct tree species were subjected to Pearson correlation, regression analysis with various climate variables including seasonal, monthly, average temperature and rainfall as well as CO_2 level, using MS Excel (Version 16.0, 2019). Moreover, Pettitt's test for homogeneity at a 5% level of significance was employed to detect change points in the time series of monthly, seasonal as well as annual temperature and rainfall parameters using the XLSTAT (2021.3.1, 2021). Similarly, the Mann-Kendall statistics and Sen's slope were also calculated using the XLSTAT 2021.3.1 to determine the magnitude of increase or decrease of climatic variables.

RESULTS AND DISCUSSION

Climatic information. In the study area, only the maximum temperature and rainy season temperature varied significantly ($P < 0.05$) from 1991 to 2017 (Figure 2). Overall, the maximum temperature increased from 24.678 °C to 25.968 °C in the early 2000s, whereas the rainy season temperature decreased sharply from 23.762 °C to 23.213 °C after 2007. Contrary to the present study, Bhutiyani (2015) suggested that the rainy season temperature varies less than the winter temperature. Only the months of January, April and November show substantial monthly average temperature variations with rising tendency [Figures S1 and S2, see the Electronic Supplementary Material (ESM)]. Similarly, the CO_2 level increased steadily from 1991 to 2017 resulting in an average shift from 364.61 ppm to 391.30 ppm in 2011 (Figure 3). However, contrary to Bhutiyani (2015), the rainfall metrics, both seasonal and monthly rainfall, did not show any significant variation (Figures 4 and S2, for Figure S2 see the ESM). The Sen's slope estimator demonstrates that the majority of the temperature variables have positive Sen's slope whereas the rainfall variables have the negative one, indicating that though non-significantly the temperature increases whereas the rainfall decreases (Table 2). Moreover, the regression analysis of the climate variables revealed that among the temperature variables, the least variation was recorded in the maximum temperature (R^2 = 0.5295) followed by average (R^2 = 0.279), rainy (R^2 = 0.235), summer (R^2 = 0.224), spring (R^2 = 0.2018), minimum (R^2 = 0.1458), winter season temperature (R^2 = 0.1249) with the polynomial fit and maximum in the autumn season temperature (R^2 = 0.0405) with the power fit (Figure S3, see the ESM). Among the rainfall variables, the maximum variation was recorded in the summer season rainfall (R^2 = 0.005) followed by the spring season rainfall (R^2 = 0.0177), autumn (R^2 = 0.057), winter season (R^2 = 0.085), total rainfall (R^2 = 0.0975) and minimum in the rainy season rainfall (R^2 = 0.112). Rainfall variables, viz. spring and season rainfall, have the power fit, while summer season rainfall has the logarithmic fit and the left three rainfall variables were modelled with the polynomial fit.

Chronology of tree ring width. We generated a chronology for seven MPTs, with *M. composita* and *G. optiva* being the youngest and oldest species at 12 and 58 years of age, respectively (Figure 5). Only *G. optiva* species, with Sen's slope of 0.033, showed a significant increasing trend in the tree ring width. However, growth rates decreased in four species, viz. *T. ciliata*, *C. australis*, *P. fortunei* and *U. villosa*, similarly like reported by Brandes et al. (2016) for *Piptadenia gonoacantha*. The increasing trend in growth rates with age in *G. optiva* may be attributed to outliers or sudden rapid rise in the growth due to favourable condi-

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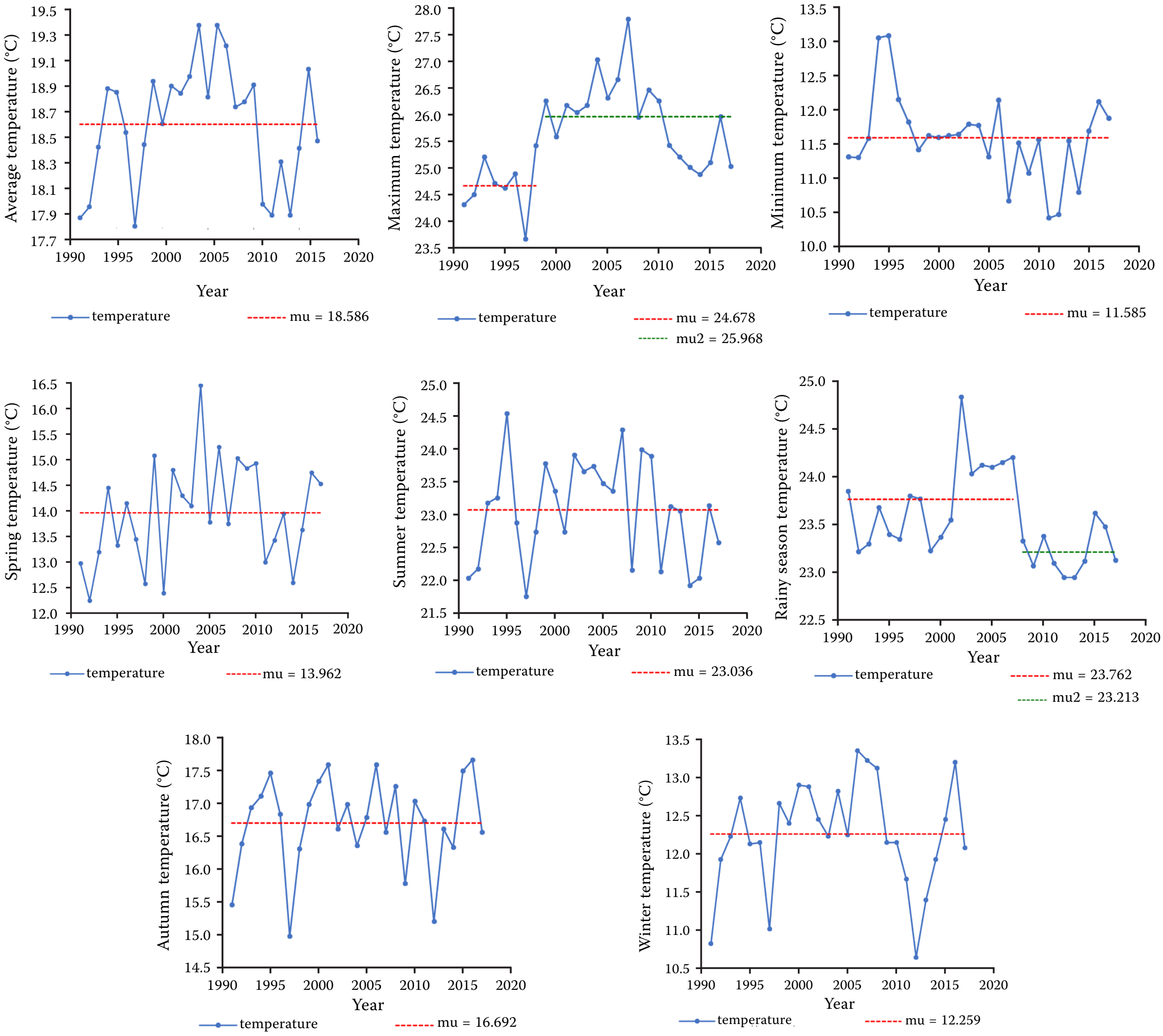

Figure 2. Time series trend analysis of different temperature attribute variation from 1991–2017 including a distinct period in the year using Pettitt's test for homogeneity

Seasons: spring – February to March; summer – April to June; rainy season – July to September; autumn – September to October; winter – November to February; mu –means for that particular period

tions, while in *C. australis* and *M. composita*, maturity or maximum growth rates have not been achieved yet. Additionally, there is less variation in the tree ring width chronology of these MPTs, mainly due to their shorter lifespan generally less than 50 years. According to the regression analysis, *P. fortunei* had the maximum variation in relative tree ring index with years (R^2 = 0.0106), followed by *U. villosa* (R^2 = 0.0691), *B. variegata* (R^2 = 0.1449), *C. australis* (R^2 = 0.2169), *G. optiva* (R^2 = 0.2285), *T. ciliata* (R^2 = 0.3572) and least in *M. composita* (R^2 = 0.4265) (Figure S4, see the ESM). *P. fortunei* had the power model fitted whereas all the remaining species had the polynomial fit. These variations in the tree chronology may be associated with the large complex physiology (Drew et al. 2013; Zang et al. 2014) and growth variability of different trees (Zywiec et al. 2017).

Response to climatic variables. The seven selected MPTs, viz. *B. variegata*, *C. australis*, *G. optiva*, *P. fortunei*, *T. ciliata*, *U. villosa*, *M. composita*, showed reaction to one or more climate variables

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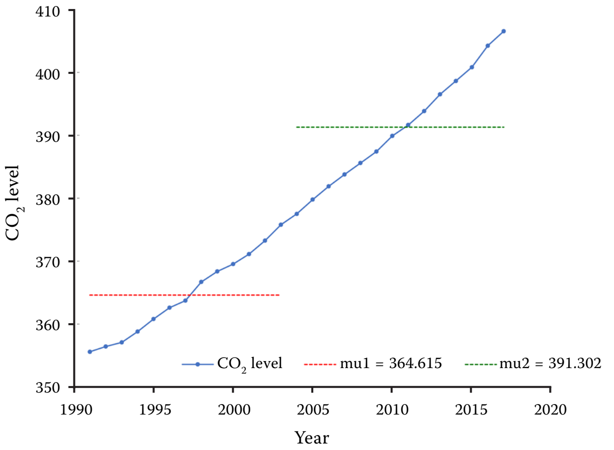

Figure 3. Time series trend analysis of CO_2 level from 1991–2017 using Pettitt's test for homogeneity

mu1 - mean before change point; mu2 - mean after change point

(Table 3), mostly owing to the complex physiology and growth variability of individual trees. Despite the distinct and datable rings, *B. variegata* showed only a negative correlation with March rainfall ($r = -0.53$, $P < 0.01$) (Figure 6). Surprisingly, *C. australis* showed a remarkable negative correlation ($P < 0.05$) with annual average ($r = -0.466$), maximum ($r = -0.491$), spring season ($r = -0.482$) (Table 3) and March ($r = -0.647$; $P < 0.01$) temperature (Figure 7); whereas a positive relationship with March rainfall ($r = 0.412$) primarily due to the preference of subtemperate climates and the ability to withstand temperature below freezing (Yadav, Bisht 2015). However, the increased temperature has a detrimental effect on *C. australis* growth, because temperature is the limiting factor for tree growth in temperate and subtemperate regions (Trouet et al. 2006).

The growth of *G. optiva* trees was significantly negatively correlated ($P < 0.05$) with winter rainfall ($r = -0.390$) (Table 3). Simultaneously, increasing temperature ($r = 0.41$) and decreased rainfall ($r = -0.50$) in the month of February had a positive influence on *G. optiva* growth and vice versa recorded in May (Figures 6 and 7). Moreover, *G. optiva* exhibited a substantial positive correlation ($P < 0.01$) with the CO_2 level ($r = 0.644$). The growth of *M. composita* is unresponsive to temperature and rainfall variables but positively ($P < 0.01$) correlated with the CO_2 level ($r = 0.596$). Similarly,

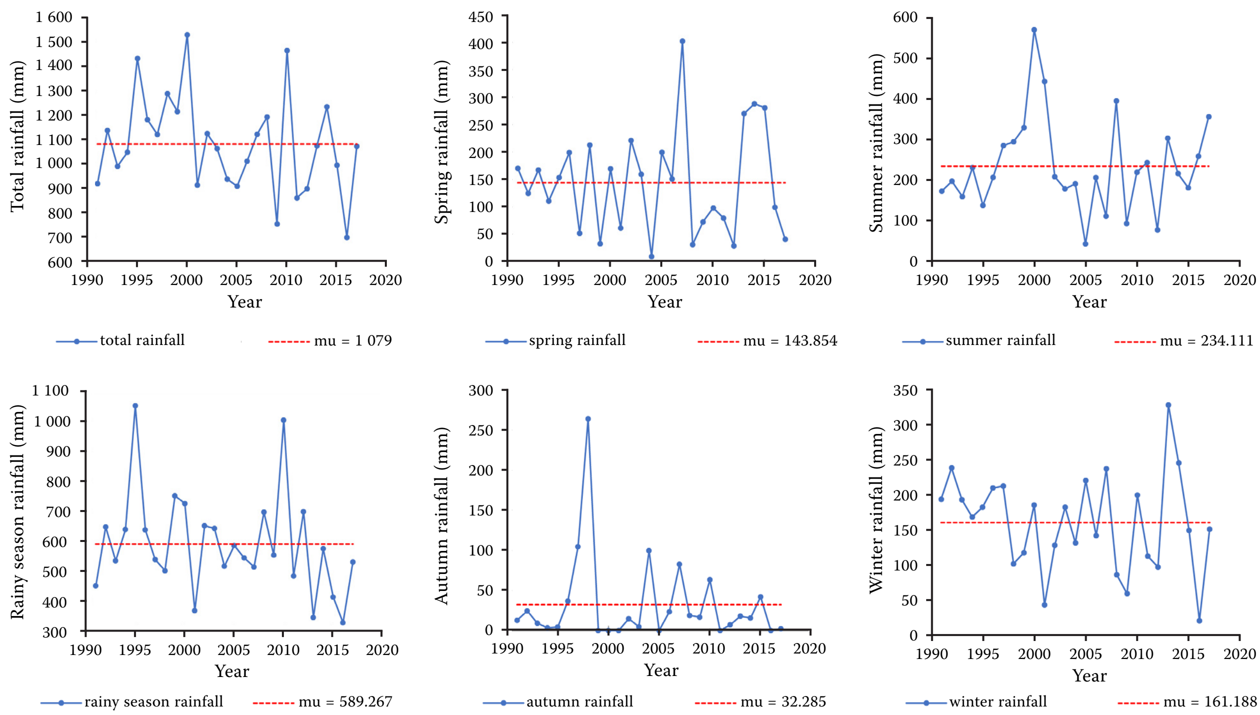

Figure 4. Time series trend analysis of different rainfall (mm) attribute from 1991–2017 including a distinct period in the year using Pettitt's test for homogeneity

Seasons: spring – February to March; summer – April to June; rainy season – July to September; autumn – September to October; winter – November to February; mu –means for that particular period

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Table 2. Sen's slope estimator for the different climatic parameters

Period	Variable		
	temperature	rainfall	CO_2 level
Average/total	0.005	–5.473	1.99
Summer	–0.005	1.206	–
Rainy	–0.012	–4.920	–
Spring	0.033	–0.520	–
Winter	0.006	–2.035	–
Autumn	0.007	–0.071	–
Maximum	–0.012	–	–
Minimum	0.035	–	–
January	0.079	–0.839	–
February	0.083	–0.657	–
March	0.109	0.323	–
April	0.067	–0.129	–
May	0.000	0.740	–
June	–0.045	–0.267	–
July	–0.017	0.292	–
August	0.000	–4.543	–
September	0.037	–1.964	–
October	0.037	0.000	–
November	0.068	0.000	–
December	0.030	0.570	–

Seasons: spring – February to March; summer – April to June; rainy season – July to September; autumn – September to October; winter – November to February

Vlam et al. (2014) reported a non-significant correlation between the total current year rainfall and tropical *M. azaderach* growth, a close relative of *M. composita.* However, Vlam et al. (2014) also reported a positive relationship of *M. azaderach* growth with the total monthly and previous year rainfall, minimum and maximum temperature (prior dry season), but the negative correlation with the current wet season monthly minimum and maximum temperature.

The *T. ciliata* chronology exhibited a positive correlation with the temperature variables, viz. rainy season temperature (r = 0.545, P < 0.01), average temperature (r = 0.405, P < 0.05) and April temperature (r = 0.40, P < 0.05). Similarly, Vlam et al. (2014) also revealed a positive correlation between *T. ciliata* and monthly maximum temperature of the preceding dry season in the tropical region. But they also found a strong positive correlation between tropical *T. ciliata* and total monthly

Table 3. Pearson correlation coefficient for the relation between the relative tree ring index (RTRI) and different climatic parameters, including a distinct period in the year

Tree species	Temperature (°C)								Rainfall (mm)						CO_2 level
	average	min.	max.	summer	rainy	winter	spring	autumn	total	summer	rainy	winter	spring	autumn	
B. variegata	–0.021	–0.105	0.044	–0.050	–0.327	0.041	0.354	–0.170	–0.091	0.233	0.172	–0.402	–0.544	–0.0408	0.022
C. australis	–0.466*	0.007	–0.491*	–0.234	–0.314	–0.256	–0.482*	–0.169	0.219	0.035	–0.013	0.340	0.283	–0.074	0.050
G. optiva	0.026	–0.015	0.041	–0.213	–0.262	0.263	0.262	0.094	–0.229	0.284	–0.219	–0.390*	–0.353	–0.197	0.644**
M. composita	0.028	0.388	–0.234	–0.094	0.026	0.128	0.084	0.180	–0.197	0.169	–0.403	–0.039	0.091	0.022	0.596*
P. fortunei	0.261	0.104	0.257	0.400	0.114	0.027	0.169	0.047	0.451*	–0.108	0.394	0.481*	0.240	0.185	–0.002
T. ciliata	0.405*	0.078	0.375	0.255	0.545**	0.288	0.271	0.105	0.085	0.255	–0.019	–0.145	–0.042	0.016	–0.093
U. villosa	–0.379	–0.298	–0.433*	–0.247	–0.132	–0.38	–0.363	–0.353	0.1244	0.069	–0.092	0.098	0.021	0.476*	–0.298

*,** P < 0.05 and P < 0.01 respectively; seasons: spring – February to March; summer – April to June; rainy season – July to September; autumn – September to October; winter – November to February

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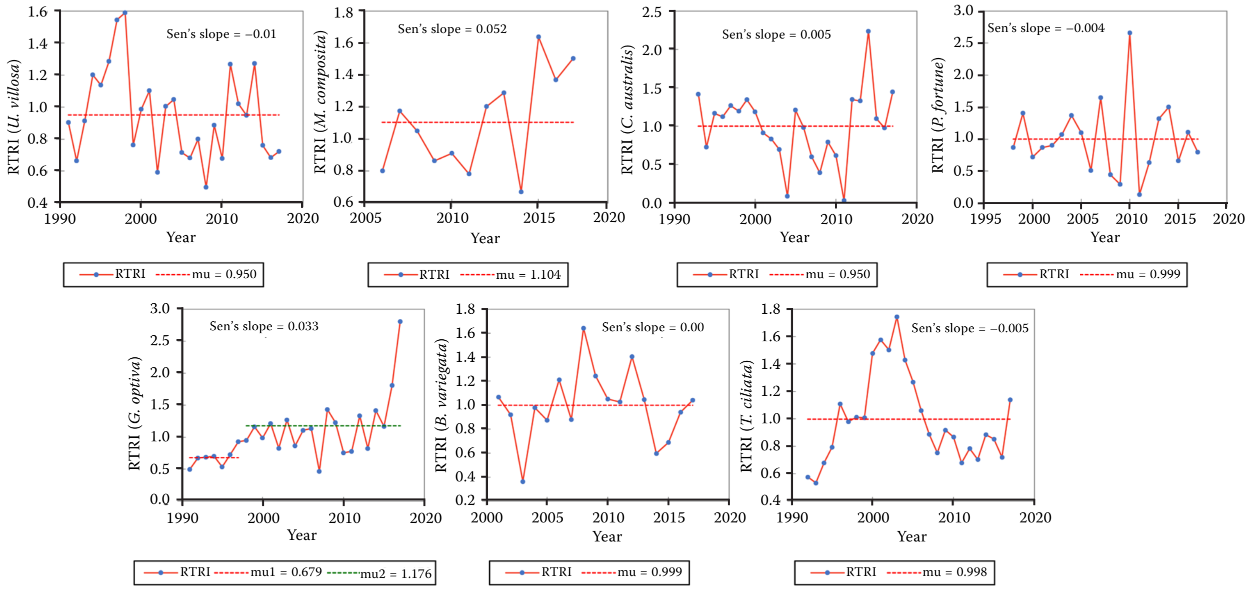

Figure 5. Chronology of the relative tree ring width index (RTRI) of the seven multi–purpose tree species using Mann-Kendall statistics

mu – means for the particular period; mu1 - mean before change point; mu2 - mean after change point

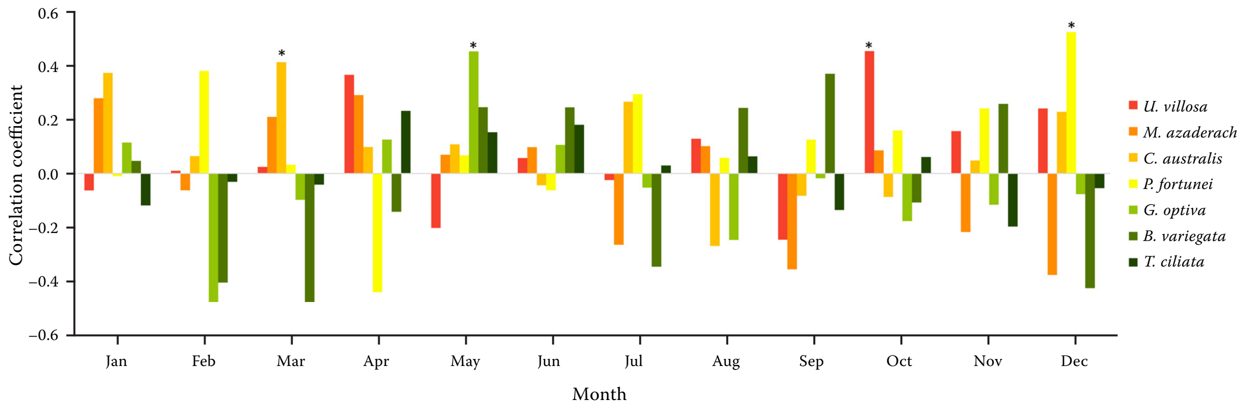

Figure 6. Pearson correlation coefficient for the relation between the relative tree ring index and monthly rainfall

*$P < 0.05$

rainfall, current and previous year rainfall, growing season rainfall and a negative correlation with the wet season monthly minimum temperature, current dry season minimum and maximum temperature. Bhattacharya et al. (1992) observed *T. ciliata* (in the tropical region) suitable for the reconstruction after the flood, mainly due to its clear, datable and climate-sensitive growth rings that record a significant reduction in tree growth induced by the narrow growth rings caused by flooding in the rainy season. Similarly, in the present study, the majority of the rainfall parameters, especially the rainy, winter and spring season rainfall, recorded the negative correlation with *T. ciliata* growth but not significant. The non-significant relation of *T. ciliata* with the rainfall parameters may be explained by its shallow root structure (Bhattacharya et al. 1992). However, Bhattacharya et al. (1992) considered solely the rainfall factor to predict the growth response since rainfall parameters are a decisive factor in the tropical region. However, for the same species *T. ciliata* the growth at higher elevations can be better described by the temperature regime than the growth at lower elevations (Savva et al. 2006), which is consistent with our results.

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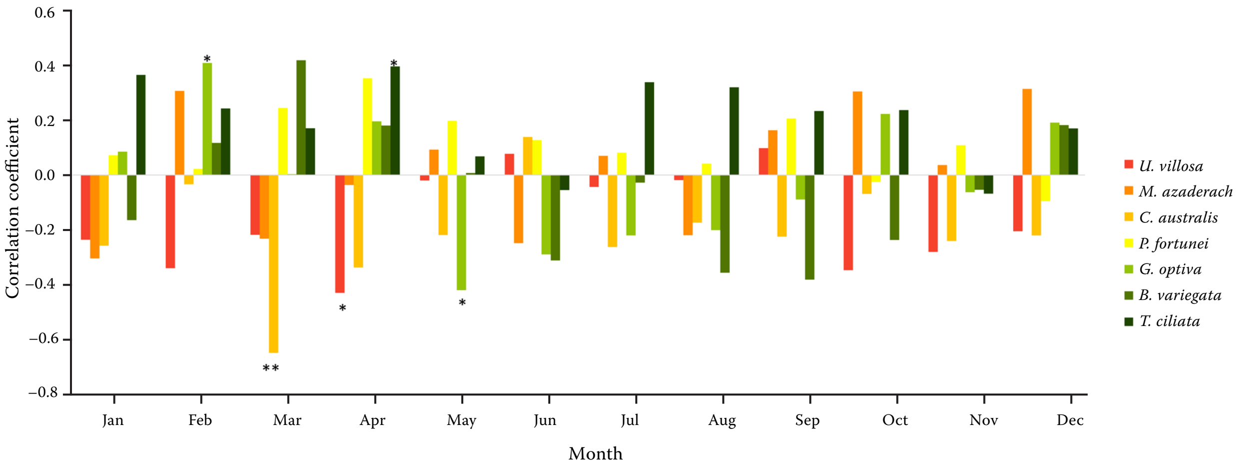

Figure 7. Pearson correlation coefficient for the relation between the relative tree ring index and monthly temperature

*,** $P < 0.05$ and $P < 0.01$ respectively

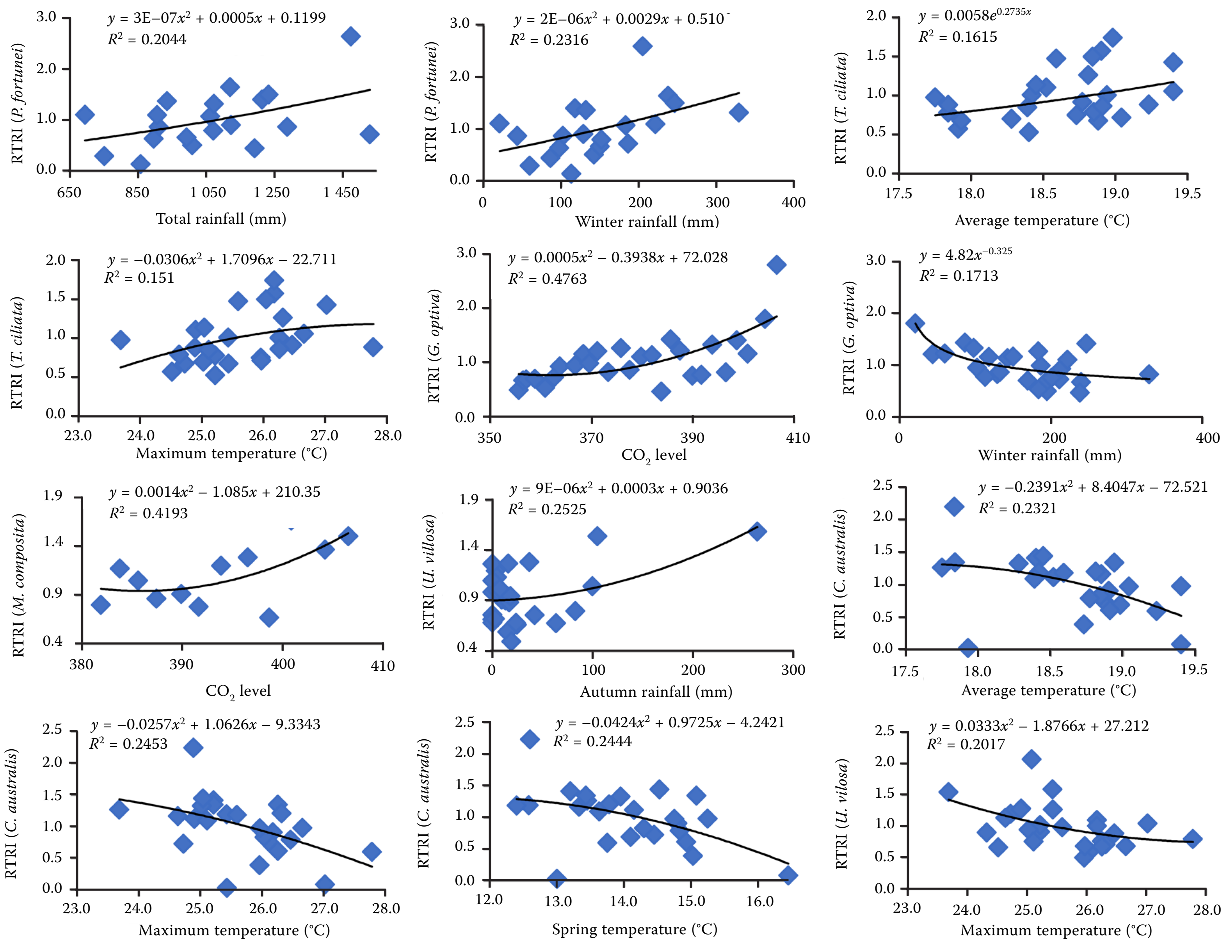

Figure 8. Relationship between the climate variables and relative tree ring index (RTRI) for the seven tree species in the north-western Himalayas which have significant correlation; on the x–axis, the climate variables during the period of the significant correlation (Table 3) with their relative tree ring index are expressed for each species

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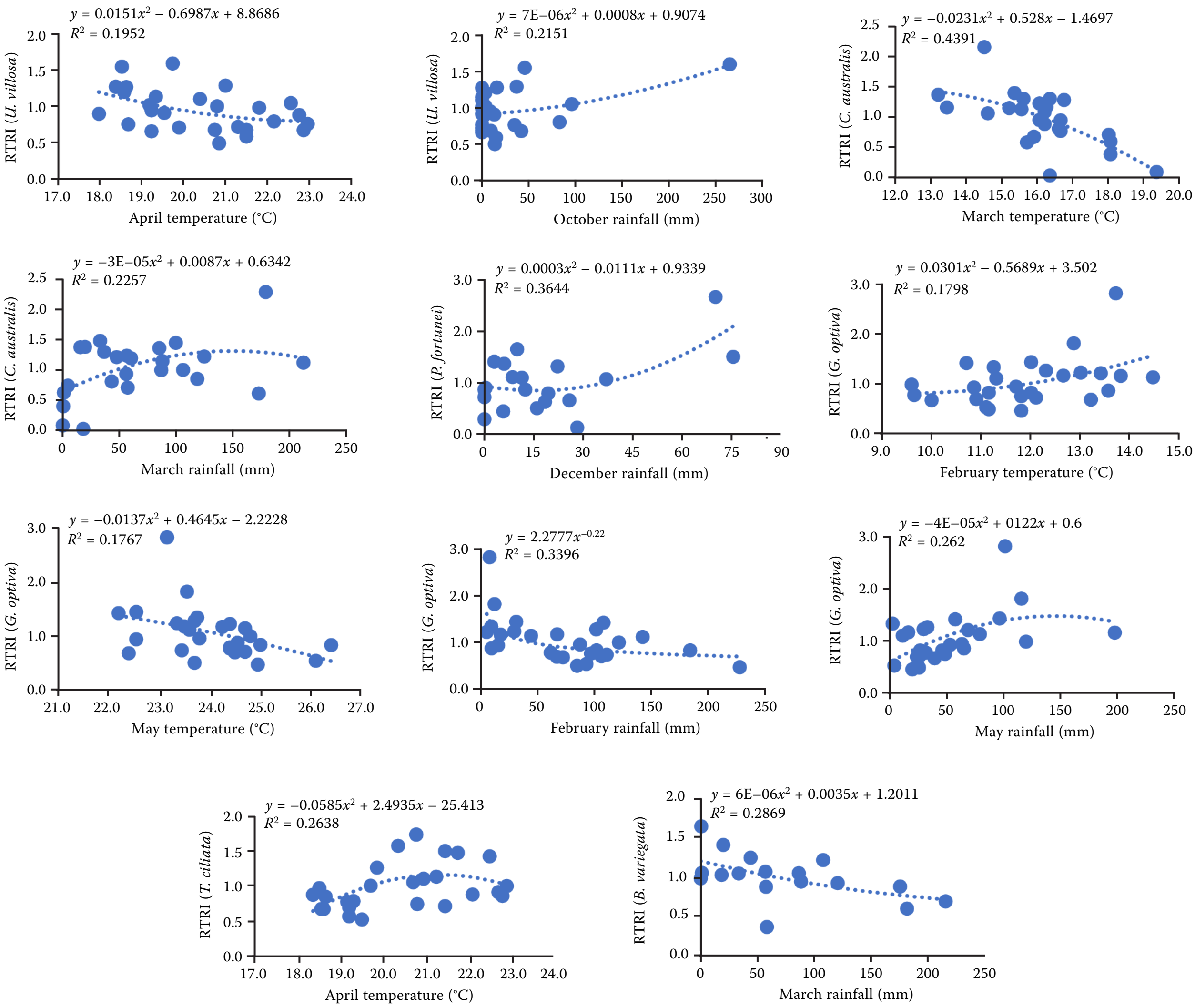

Figure 9. Relationship between the monthly climate variables and relative tree ring index (RTRI) for six tree species in the north-western Himalayas which have significant correlation; on the x–axis, the climate variables during the period of the significant correlation (Figures 5 and 7) with their relative tree ring index are expressed for each species

Furthermore, in case of *P. fortunei*, the rainfall variables are decisive factors, especially winter rainfall (r = 0.481), total rainfall (r = 0.451) (Table 3) and December rainfall (r = 0.52) (Figure 6). *P. fortunei* is drought resistant, but higher moisture can promote its growth (Zhu et al. 1986). Similarly to the present study, Jin-gen (1987) revealed that the cumulative temperature of more than 10 °C and rainfall are major factors affecting the growth of *P. elongata*. On the contrary, Zhu et al. (1986) stated that the growth of *P. fortunei* is closely tied to temperature and it benefits from a higher temperature regime. *U. villosa* demonstrated a positive correlation (P < 0.05) with autumn rainfall (r = 0.476) (Table 3) and October rainfall (r = 0.451) (Figure 6), whereas a notable negative correlation with maximum temperature (r = –0.433) (Table 3) and April temperature (r = –0.428) was recorded (Figure 7). Similarly, Brett (1978) reported that rainfall during early winter (September to December) had a direct influence on the growth of *Ulmus* spp. but rainfall during the previous summer and temperature during March and April had the inverse effect. Apart from temperature and rainfall variables, increasing CO_2 levels had a significant effect on just two species, viz. *G. optiva* (r = 0.644, P < 0.01) and *M. composita* (r = 0.596, P < 0.05). Similarly, Voelker et al. (2006) reported that the elevated CO_2 levels had a favourable effect on the tree growth. However, for three MPTs (*P. fortunei*,

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T. ciliata and *U. villosa*), the correlation was negative, although not significantly confirmed, which is also supported by Tognetti et al. (2000). The relationship between the relative tree ring index chronologies of the six species and the climate variables which are significantly correlated in both directions is illustrated in Figures 8 and 9.

CONCLUSION

Our results demonstrate that the growth in the selected seven MPTs is at least partially determined by the climate variables. However, the effect of rainfall variables in terms of the correlation coefficient is less significant than the effect of temperature variables. Especially the average and maximum temperature had the greatest effect on the growth of MPTs, particularly *C. australis, T. ciliata* and *U. villosa*. Also, among the seven investigated species, *G. optiva* shows the excellent potential for the development of the climate-sensitive chronologies in the northwestern Himalayas whereas *B. variegata* provides the least. Our findings will contribute to a better understanding of the climate growth relationships, and to predict the effects of climate change on these MPTs in the northwestern Himalayas. However, in the present selection of relatively young trees, few samples and availability of the climate data only for a definite period (1991–2017) can limit its use for accurate representation but can definitely help in directing the future studies in the region. Simultaneously, in future, there is a need to identify new species and to integrate other unique ring features like wood anatomy, chemistry, density or quality that can complement and foster the existing dendrochronological studies in the northwestern Himalayas.

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