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Assessing Diameter Growth in Conifers and Relation with Bioclimatic Variables under Temperate Conditions of Western Himalayas

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Abstract: The current study was taken to assess average annual growth rate put on different conifer species (*Abies pindrow, Cedrus deodara, Picea smithiana* and *Pinus wallichiana)* under varying climatic variables including temperature, precipitation and relative humidity over a period of 10 years using multiple regression approach. A general response of average increment per year under different diameter classes viz. 1 (10-30) cm, 2 (31-50) cm, 3 (51-70) cm and 4 (71-90) was also assessed using standard tree increment core method. Ninety-six core samples were extracted from the selected trees and analysed for tree ring widths according to standard dendrochronological procedures. *Cedrus deodara* showed highest average annual increment of 6.32mm, while as *Abies pindrow* showed the lowest annual increment with 4.31mm over the period. Average annual increment of diameter class 2 (31-50cm) was highest (5.53 mm) irrespective of species and sites while as the lowest was observed for class 3 (4.81 mm) and 4 (4.85 mm). Response of average annual increment to climatic variables was best explained for *Cedrus deodara* (R^2 = 0.62) while as diameter class 2 best explained the response to climatic variables with R^2 (0.92). The regression models developed for different species and diameter classes were validated through predicted models having close coherence with the observed values. The study addresses data gaps and offers potential to predict biomass carbon accumulation under the changing climatic conditions.

Keywords: Increment, Conifers, Bioclimatic variables, Wood core sample, Kashmir Himalayas

Tree growth also referred to as increment is one of the most important biophysical variables' that contributes to biomass accumulation (Vieira et al 2020). Tree growth prediction has become important in view of its direct relation to productivity and dynamics of forest stands (Condit et al 2006) responds to temperature changes across the latitudinal gradient in the same way it responds to altitudinal gradients in the mountainous areas (Lyu et al 2017). There is an inconsistency in tree growth responses to climate with varying geographic location, forest type, and tree species (Rahman et al 2018).

There is a considerable decrease in duration and rates of xylem cell production due to drought conditions resulting into declined wood production (Vieira et al 2020). Cambial activity is hugely influenced by the existing environmental and physiological conditions including phenological stage, soil water availability, precipitation, temperature levels and on the number of sunlight hours per day. These factors increase the rate of photosynthesis when present in optimum amount. Climatic conditions especially water availability triggers cambial activity that leads to increase in tree girth and other wood characteristics (Drew et al 2009, Sette Jr 2016). Diameter has been extensively used and monitored to study the increment of trees due to its more pronounced relation with the growth. Moreover, diameter can be measured easily with a higher accuracy compared to tree height (Ishihara et al 2016). Species based on existing environmental drivers, local adaptations and individual plasticity to climate respond to climate by adjusting the timing and extent of their phenology, growth and reproductive seasons (Diez et al 2012). Past growth dynamics at the tree treeline in response to changing climatic conditions and climatic variability are the ready references to know tree population dynamics (Jochner et al 2017).

Besides the inherent factors of species that control growth rate, seasonality of cambial activity is influenced significantly by temperature (Drew et al 2009), photoperiod and precipitation (Marcati 2006, Drew et al 2009). Temperature and water availability are known to regulate growth and cambial activity (Drew et al. 2009). Thus tree ring analysis has been proven as a helpful technique to assess age and growth pattern of tree species over long time periods Rozendaal et al 2011).

Dendrochronology in the recent years has developed as a sophisticated science and its full potential is yet to be explored (Aryal et al 2018, Jawad and Ahmad 2021). Moreover, in context of REDD+, this quantification is prerequisite for assessment of forest biomass and carbon sequestration in turn. In addition, this relation helps to explore forest ecosystem capacity to adapt climate change (Wani et al 2019, Joshi et al 2022). Temperate Himalayan region is mainly composed of evergreen species including *Pinus wallichiana, Cedrus deodara, Abies pindrow and Picea smithiana*. They form the major strata that contribute to biomass carbon in the region and incremental data in these species is utterly lacking in the region (Wani et al 2019) and must be estimated using indirect methods in the absence of any reliable data. In this study, it was hypothesized that the increments put on by different conifers vary significantly in terms of diameter under a given set of climatic conditions.

MATERIAL AND METHODS

Study area: Special Forest Division, Tangmarg is spread across three districts of Jammu and Kashmir including Baramulla, Budgam and Srinagar (Fig. 1). The forest area primarily lies in district Baramulla between Longitude: 74˚16´E to 74˚46´E and Latitude: 33˚54´N to 34˚17´N as shown in Figure. 1 envisaging world famous skiing resort Gulmarg. It experiences pleasant weather in summer and severe cold in winter. Winter precipitation is mostly received in the form of snow by almost all parts of the district.

Sampling design and collection: Purposive random sampling technique was adopted within the study area. Core samples were collected from the dominantly identified species in the study area. Three sites viz. Site I or C1 (Baderkoot and Gogaldara), Site II or C2 (Kalantra and Baba Reshi) and Site III or C3 (Tangmarg and Gulmarg) were selected based on purposive random sampling from the study area. The sites varied from each other in terms of location an altitude with Site I (34° 02' 15.9" N; 74° 27' 26.7" E) at average altitude of 2206 m amls, Site II (34° 06' 02.4" N; 74° 23' 54.9" E) at an average altitude of 2011 m amsl and Site III (34° 02' 16.2" N; 74° 24' 28.5" E) at an average altitude of 2261 m amsl. From each site, core samples were taken from four conifers viz. Deodar (*Cedrus deodara)* (B1)*, Blue Pine (Pinus wallichiana)* (B2)*, Fir (Abies pindrow)* (B3) and *Spruce (Picea simithiana)* (B4).

With the help of increment borer, a small pencil sized piece of wood known as tree core, core sample or increment core was taken from the trunk of tree at breast height (1.37 metre above ground level). The trees were bored using 5 mm increment borer in accordance with (Jochner 2017). At least two cores were taken 90 degrees away at any point of measurement using increment borer. Core samples at each site were obtained in four diameter classes viz. 10-30, 31-50, 51-70 and (71-90) cm. The borer was inserted to a depth so that at least last 10 growth rings (i.e., from 2018 year of sampling to past 10 years of radial increments) were obtained on the radial core. Cores collected from 96 trees in the study area were immediately secured in core tubes with proper labelling and transferred to the laboratory for analysis. Annual radial increments from each core sample were recorded in synchronization with the respective tree DBH (diameter at breast height). Annual radial increments were doubled for calculation of annual growths or annual diameter increments or growth rate. Simple stereomicroscope was used for measurement of annual ring measurements using standard dendrochronological procedures (Fritts 1962). Repeated measurements were taken up to a resolution of 0.1 mm and then averaged for the final measurement.

Species, climate and growth: To identify the synergistic effect of the climatic variables on the increment, tried multiple regression analysis and generated models for prediction of diameter increment in different species. The response of increment was also assessed under different diameter classes for conifers in general. Prediction models were developed for different species and different diameter classes with the climatic variables as the dependent variables. Specifically, tree ring data and climate data was combined to figure out the following queries:

1. How the climatic variables of area determine the diameter increment of individuals in a species?
2. How different species respond to the same environmental factors prevailing in a locality?
3. How diameter increment varies in different diameter classes of the species?

Species wise diameter increments of trees from all the sites over a period of 10 years in corresponding diameter classes were tabulated and subjected to multiple regression analysis with average annual temperature (°C), mean annual precipitation (mm) and average annual relative humidity (%) as the independent variables using the climatic data of the region obtained from Indian Meteorological Department Srinagar. Coefficient of determination (R^2) was also calculated for each model. Graphically individual line fit and residual plots for different species and diameter classes were plotted to spot patterns and trends with individual climatic variables. These plots also represent the interaction of different multiple regression models and associated error with individual climatic variables.

RESULTS AND DISCUSSION

The diameter increments of *Cedrus deodara, Pinus wallichiana, Abies pindrow* and *Picea simithiana* over a period of 10 years reveals that the average diameter increment of *Cedrus deodara* ranges from 5.75 to 6.83 in 2014 and 2009 The average diameter increment of *Pinus wallichiana* ranges from 4.65 to 5.11 mm in 2009 and 2013

The average diameter increment of *Abies pindrow* ranges from 3.81mm (2018) to 4.74 mm (2014). The average diameter increment of *Picea smithiana* ranges from 4.07 mm (2017) to 4.93 mm (2013). Similarly among the diameter classes the increment under diameter ranged from 5.88mm (2013) under class 1 to 4.08mm (2018) under class 3. The diameter increment was found highest in *Cedrus deodara* (6.83 mm) for year 2014 while lowest was in *Abies pindrow* (3.83 mm) for 2018. Average annual temperature ranged from 7.71°C (2013) to 6.25°C (2009). Mean annual precipitation ranged from 4.86 cm (2015) to 1.05 cm (2010) while as average annual relative humidity ranged from 80.13 % (2013) to 64.78 % (2009).

In models, 'Y' denotes diameter increment (mm), 'β_0'denotes average annual temperature (°C), 'β_1' denotes mean annual precipitation (cm) and 'β_2' denotes average annual relative humidity (%) (Table 2). With these models, for any year annual diameter increment of any of these four species and in any diameter class in general can be calculated using the given set of climatic variables for the given region. Among the species, highest R^2 was for Deodar (0.62) followed by Fir (0.57) while as among different diameter classes the highest R^2 was estimated for D2 (0.92) followed by D3 (0.53) (Table 2). These higher values depict comparatively strong relations for the given set of variables. The models generated for each set of relations were also validated by generating predicted models for each species and all the diameter classes (Fig. 1 a-b). There was proximity between the predicted and observed values for each set of relation for species (Fig. 2a-o) with and diameter classes (Fig. 3a-l). Measures of central tendency for the diameter class 1-4 are shown in Figure 1 a-b.

The active growth period in Himalayan conifers ranges from March to October. Generally, the new shoots appear in March and early April. The xylem cells grow faster under optimum moisture conditions during the active growing season and hence are deemed important for annual growth in trees. Precipitation in the form of rain and snow is majorly received in winter months which makes the moisture available to plants in their early growing period. The conifer species indicate strong climatic signatures in ring-width measurement series, however, there is always a paucity of climatic data in mountainous region which makes it difficult to

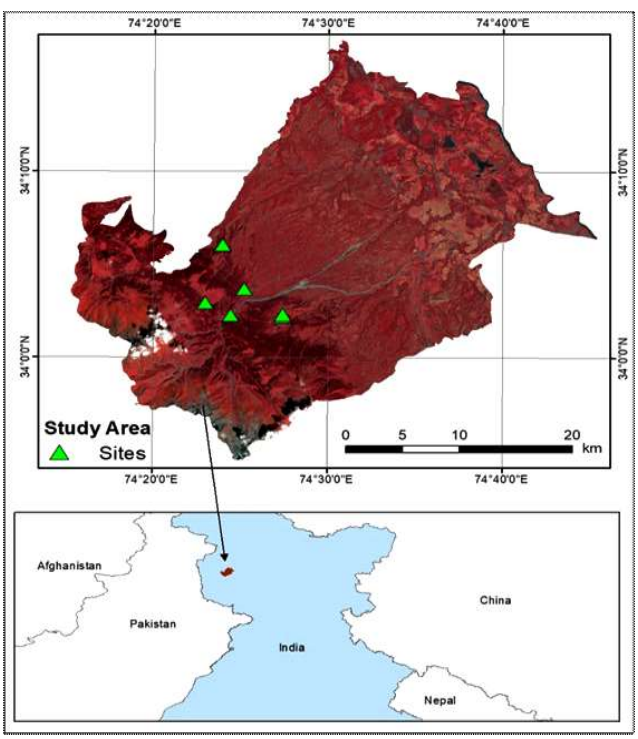
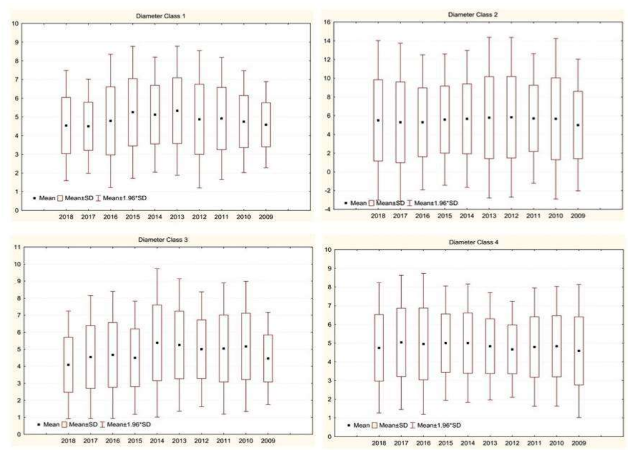
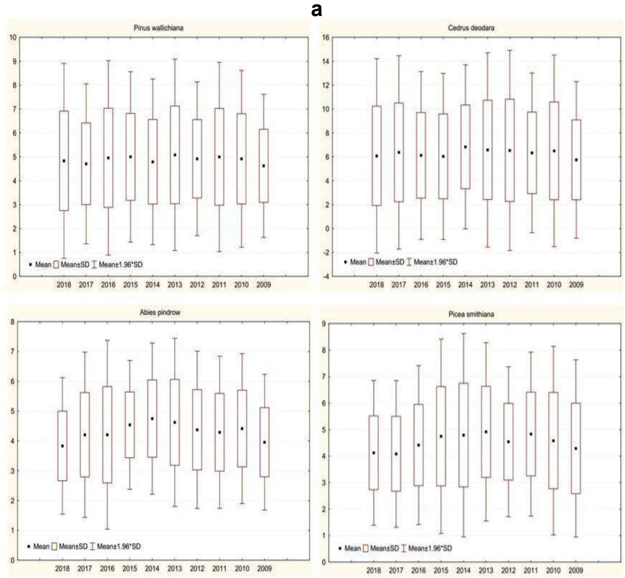


Fig. 1. Study area



a



b

Fig. 1. Statics for the diameter class 1-4

calibrate tree-ring data with climate (Dhyani et al. 2023). The diameter increment is generally considered as a growth indicator in trees. It depends on many factors which ranges from difference in genotypes among species to factors of locality affecting trees. Therefore, annual diameter increment can vary from species to species, among individuals in a species and annual year growths in an individual (Chen et al 2022).

The diameter class 1, 2 and 3 registered higher growth rates when the climatic variables were on higher side while only diameter class 4 showed lowest growth rate when the climatic variables were on lower side. There was strong correlation between diameter increment and climatic variables for diameter class 2 with R^2 of 0.92. The different diameter classes respond differently to climatic variables in terms of different growth responses. Merian and Lebourgeois (2011) also observed established a relation between tree diameter sizes and their climate growth responses. They further revealed that contrasting diameters of a species behave differently to climate-growth responses and large sized trees could be heavily influenced by climate change especially under xeric conditions. The reasons could be the variable resource availability per unit biomass across different sizes of the trees as the tree growth is liners to leaf biomass (Enquist et al 1999). However, this is true for symmetric competition and may not always be tree for asymmetric competition especially closed forests where smaller trees are consistently under shade of the dominant trees (Muller-Landau et al 2006). However, as explicit, the growth rates in the present study are averaged over a diameter class and doesn't reflect growth characteristics of individual trees subjected to crowdedness (tree density) (Fransson et al 2021) and level of disturbance (Muller-Landau et al 2006, Coomes et al 2011). Sette Jr (2016) reported that higher trunk growth rate was observed in larger trees than in other basal area classes in *Eucalyptus grandis,* while studying relationship between climatic growth rate, trunk growth rate and wood density. Gao et al (2020). In his study revealed that there was no significant difference in growth response to climate.

During 2013 to 2015, the climatic variables were on higher side and all the species registered highest diameter growth rate and from 2009 to 2010, the climatic variables were on lower side, only *Cedrus deodara* and *Pinus wallichiana* registered comparatively less diameter increment while as *Abies pindrow* and *Picea smithiana* continued to grow with average growth rate. Ram and Borgaonkar (2014) also observed climatic responses of tree rings of fir (*Abies pindrow*) in western Himalayas and concluded that relationship between diameter growth rate and climatic variables were significant positive r due to moisture availability through snow melt in the growing seasons when physiological processes are at its peak.

The current study indicates that different conifer species growing across the study area have different abilities to fix increments under a given set of climatic variables and varied biophysical parameters under different sites. Marquardt et al (2019) while studying climatic response of growth in Sky Island Ponderosa pines demonstrated that dendroclimatic response varies modestly between species and sites. Hughes et al (2019) also observed that diameter growth rate of pine was positively correlated with early summer total

Table 1. Species wise and diameter class wise diameter increment (mm) and climatic variables in a decade (2009-2018)

Year	Diameter increment (mm)					Diameter classes				Climatic variables		
	Dia Increment (mm) Deodar	Pine	Fir	Dia increment (mm) Spruce	Average annual diameter increment (mm)	Average annual diameter increment (mm) D1	Average annual diameter increment (mm) D2	Average annual diameter increment (mm) D3	Average annual diameter increment (mm) D4	Average annual temperature (°C)	Mean annual precipitati on (cm)	Average annual relative humidity (%)
2018	6.08	4.83	3.83	4.13	4.72	4.54	5.50	4.08	4.75	6.30	3.25	70.49
2017	6.38	4.71	4.21	4.08	4.84	4.50	5.38	4.54	5.04	6.87	3.79	74.73
2016	6.13	4.96	4.21	4.42	4.93	4.79	5.21	4.67	4.96	7.16	2.67	69.84
2015	6.04	5.00	4.54	4.75	5.08	5.25	5.67	4.50	5.00	6.30	4.86	76.78
2014	6.83	4.79	4.75	4.79	5.29	5.13	5.79	5.38	5.00	6.42	3.94	77.06
2013	6.58	5.08	4.63	4.92	5.30	5.33	5.88	5.25	4.83	7.71	2.77	80.13
2012	6.54	4.92	4.38	4.54	5.09	4.88	5.71	5.00	4.67	7.10	4.11	78.40
2011	6.33	5.00	4.29	4.83	5.11	4.92	5.75	5.04	4.79	7.40	2.67	79.66
2010	6.50	4.92	4.42	4.58	5.10	4.75	5.75	5.17	4.83	7.23	1.05	75.44
2009	5.75	4.63	3.96	4.29	4.66	4.58	5.04	4.46	4.58	6.25	4.89	64.78

precipitation in Spruce and Pine forests of northern European Russia. The current study results are in accordance with observations on species growth relations with temperature for *Pinus wallichiana* (Shah et al 2019), multi-species (Wettstein et al 2011) *P. abies* (Andreassen et al 2006), *Larix olgensis* (Shen et al 2016) and *Betula tortuosa* (Petrov et al 2019). Bolivian tropical lowland forests (Toledo et al 2011) *Larix decidua* (Carrer and Urbinati 2006). Ram and Borgaonkar (2014) reported that correlation coefficients between growth rate and temperatures in case of *Abies pindrow* were observed to be weaker but barely significant in fir (*Abies pindrow*) from Chandanwadi in Jammu and Kashmir, western Himalaya, India.

Rahman et al (2018) inferred stronger relations in the period 1986-2015 than during 1950-1985. Climate sensitivity changes were attributed to a warming trend in the recent decades. The increase in temperature at higher elevations increases growth, however climate change can possibly influence this forest growth dynamics positively or negatively (Jochner et al 2017). Climatic variables over a long period of time affect different biophysical factors and composition of the forests which have the potential to affect growth of the trees and the same has been established (Morin et al 2018). Using dendro-ecological approach, Latreille et al (2017) concluded that growth in Silver Fir is related to the current and previous year climatic variables and besides climatic variables other factors including competition, microsite conditions including soil moisture, slope steepness, solar radiation are related to species increment.

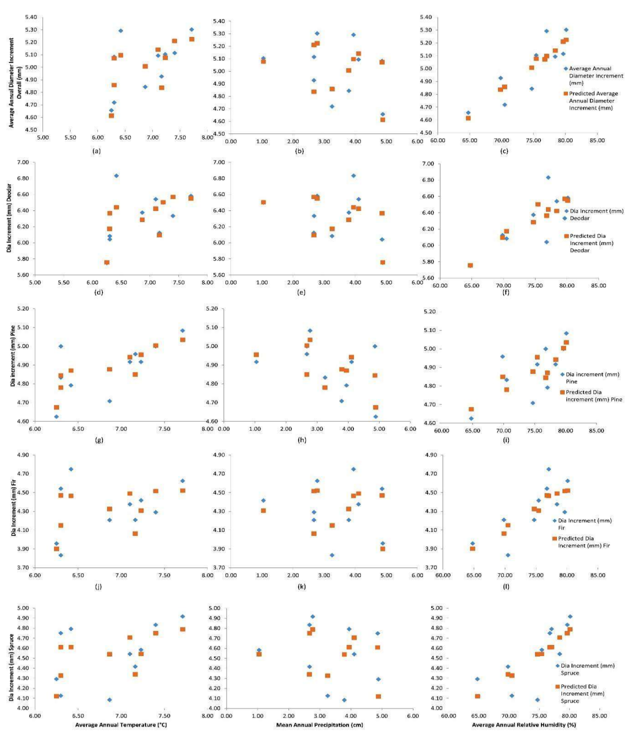


Fig. 2. Diameter increment (mm) relation with climatic variables

Table 2. Regression models developed with increment as dependent variable and climatic factors as independent variables

Species	Model	R^2
Overall	$Y=2.266-0.008\beta_0-0.017\beta_1+0.038\beta_2$	0.75
Deodar	$Y=3.526-0.109\beta_0-0.081\beta_1+0.051\beta_2$	0.62
Pine	$Y=3.342+0.081\beta_0-0.014\beta_1+0.014\beta_2$	0.56
Fir	$Y=1.135-0.059\beta_0+0.011\beta_1+0.048\beta_2$	0.57
Spruce	$Y=1.060+0.056\beta_0+0.017\beta_1+0.041\beta_2$	0.51
D1	$Y=1.281+0.038\beta_0+0.069\beta_1+0.1041\beta_2$	0.50
D2	$Y=2.912-0.224\beta_0-0.087\beta_1-0.060\beta_2$	0.92
D3	$Y=0.435+0.179\beta_0-0.041\beta_1+0.044\beta_2$	0.53
D4	$Y=4.680-0.132\beta_0-0.034\beta_1+0.016\beta_2$	0.18

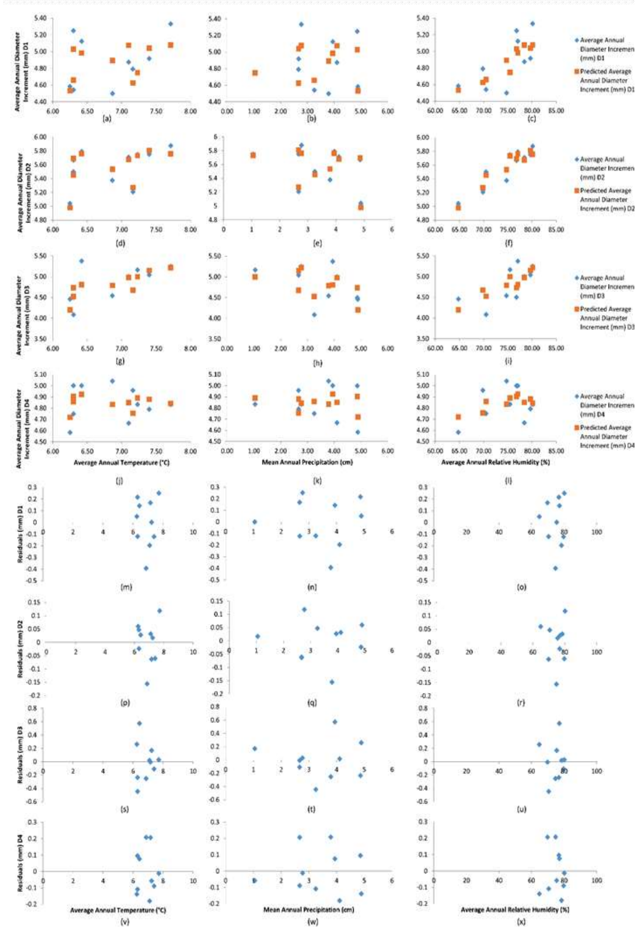


Fig. 3. Regression analysis of diameter increment (mm) with climatic variables (a-l) and residuals (mm) (m-x)

CONCLUSION

Among species *Cedrus deodara* showed a highest average growth rate of 6.32mm/year over a period of 10 years while *Abies pindrow* showed the lowest over a period of 10 years. Average diameter increment of diameter class 2 was found highest irrespective of species and sites while the lowest average diameter increment was observed for diameter class 3 and 4.Diameter class 1, 2 and 3 registered higher growth rates when the climatic variables were on higher side while only diameter class 4 showed lowest growth rate when the climatic variables were on lower side. Prediction models (species wise and diameter class wise) developed for increment relation with climatic variables fairly predict increment (growth) under said climatic variables. The hypothesis that different conifer species in the geographical region put up similar growth has been proven otherwise. Further the average increment put on by conifers in general over the time showed significantly different results for different diameter classes refuting the hypothesis. Among the species *Cedrus deodara* (Deodar) distinctly exhibited highest growth among the species and diameter class (2) expressed the highest growth among all diameter classes in general.

Diameter increment relation with the climatic variables (precipitation, temperature and relative humidity) was best explained for *Cedrus deodara* followed by *Abies pindrow* while as this relation in terms of diameter classes was best explained for diameter class 2. Higher coefficient of determination expresses the strength of relations with the given set of variables. In general, the relation of species and diameter with climatic variables had a proximity with an acceptable R^2expressing coherence between predicted and observed values.

The study could have incorporated other climatic factors as well into the study to have a more comprehensive study. However, due to lack of past data on other factors including atmospheric CO_2, nitrogen deposition, sunshine hours etc. which have the capability to influence the growth and increment. However, the study indicates that response of temperature and precipitation continue to be the driving force for positively influencing the growth of conifers in the region. Although the study doesn't use very high-quality measurement technique for ring measurement, there might have introduced some unavoidable errors in measurements, but findings of the study give reasonably good results. The study addresses the data gap that existed in the region in terms of increment studies conducted on conifer species and diameter classes. Moreover, the study demonstrates the potential of tree ring analysis to assess the relationship of past growth with climatic variables which would help predict future growth under the changing climate scenario.

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AUTHOR's CONTRIBUTION

AAW and UM initiated and conceptualized the study. All authors (UM, AAW, AAG, SM, MAI, AF, SF, IAS) contributed to field data collection and lab work. UF, AAW and IAS contributed to data evaluation. All authors (UM, AAW, AAG, SM, MAI, AF, SF, IAS) contributed to writing and reviewing the manuscript.

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