Research Article

Climate-Growth Response Function of the Blue Pine (*Pinus Wallichiana)* in Galies Forest Division-Abbottabad, KP, Pakistan

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Abstract | Climate change is a global phenomenon manifested in rising temperature, erratic changes in precipitation and other climate variables. To assess such impacts, climate-growth response function of the Blue pine (*Pinus wallichiana)* was studied in Galies Forest Division -Abbottabad, Khyber Pakhtunkhwa, Pakistan, for the time period 1962-2011. Time function response and impacts of changing climate were estimated on the basis of annual ring-width and intra-ring wood formations. The results showed mean ring-width of 2.54±0.11 mm/annum with mean sensitivity and coefficient of variation of 0.38 and 19.50%, respectively. Overall, a decreasing trend was observed in ring-width. The largest mean ring-width was 3.33±0.31 mm, while the smallest ring-width was 1.85±0.27 mm. The mean intra-ring early wood formation was 75.56±0.21%, while the intra-ring late wood formation was 24.44±1.95%. The highest growth in ring-width and intra-ring early wood formation was recorded during 1962-71, while that of intra-ring late wood formation was recorded during 2002-11. The impact of maximum temperature and minimum temperature on ring width was negative and highly significant ($p<0.01$) and of precipitation positive and non-significant ($p>0.05$). The study showed a negative growth response of annual growth ring-widths and intra-ring early wood formation and a positive growth response of intra-ring late wood formation of *Pinus wallichiana* to rising temperatures. These results suggested that the use of ring-widths combined with intra-ring wood formations enables better assessment of impacts of climate change on tree growth. It is recommended that climate change projections and scenarios may be made an integral part of Forest Management Plans for making realistic wood volume and yield estimates.

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Introduction

Climate change is a global phenomenon and Pakistan is no exception to it. Pakistan has experienced gradual increase in temperature over land and sea, fluctuations and variations in precipitation, increased frequency of climatic extremes and changes in wind and storms patterns. Moreover, the exact magnitude and frequency of these changes are not uniform in time and space (Bukhari and Bajwa, 2011; Bukhari and Bajwa, 2012; Sheikh et al., 2012).

Temperature and precipitation, two of the climatic factors bound to change with increased greenhouse gases concentrations, are primary determinants of global vegetation patterns with significant impacts on forest ecology (including biodiversity), plant distribution, productivity and health (Spurr and

Barnes, 1980; Smith and Tirpak, 1989; Bukhari and Bajwa, 2012). Increase in temperature will not necessarily have simple linear impacts on growth of tree species in different habitats (Carter, 1996). Thus, local, regional and global changes in temperature and precipitation can influence the occurrence, timing, frequency, duration, extent and intensity of climatic disturbances (Baker, 1995; Turner et al., 1998).

Pakistan is a forest deficit country with about 4.6 million ha forests and forest plantations. The per capita forest is 0.03 ha which compares unfavorably with average world per capita endowment of 0.6 ha. Among different forest types, conifers spread over about 1,946,000 ha, The temporal climate data, including Azad State of Jammu and Kashmir (AJK) and Northern Areas (Gilgit-Baltistan). These forests have multiple uses. One of the dominant species in coniferous biome in Pakistan is the Blue pine (*Pinus wallichiana*). These forests are playing vital role in national economy and ecology. Apart from production of timber and non-timber forest produces, the forests are providing livelihoods to summer grazers and forest dependent communities and serving as catchment areas of the Indus River System. The region is also important for eco-tourism due to their spectacular landforms and greenery (Bukhari, 2011; Wani et al., 2004).

The functioning and productivity of forest ecosystems are highly dependent on climatic factors. Therefore, any climate change over these forests will have significant effects on their productivity, environmental services and contribution to national economy. It is, therefore, imperative to assess the impacts of climate change on growth of high valued tree species which will help estimating the direction and quantum of these changes and devising a strategy for sustainable management of the forests.

There are several methods to assess climate change-growth response of tree species, including maintaining growth plots and recording data on visible growth parameters, such as, diameter, plant height, etc., over longer period of time. Contrarily, climate-growth response of tree species can be assessed more accurately and efficiently by measuring the ring-width and wood formation within the growth ring (Ahmed et al., 2010). Keeping above facts in view, the present study was conducted to assess (i) growth response function through ring-width and ring-wood characteristics and (ii) impacts of changing climate on growth of *Pinus wallichiana* in Galies Forest Division-Abbottabad, Khyber Pakhtunkhwa, Pakistan.

Materials and Methods

The study was conducted in Galies Forest Division Abbottabad (GFD), located between 33°50´ and 34°23´ N, 73°35´ and 73°31´ E, in northern Pakistan (Figure 1). The division was rich in biodiversity with forest cover of 37.6% (of total area of the Abbottabad district); *viz.,* Moist Temperate 26.3% and Sub-Tropical Chir pine 9.2%. The Division was important for dendro-climatological studies by virtue of its location at the boundary between tropical and temperate continental climatic interaction (Fowler and Archer, 2006).

Climate data of Climate Research Unit (CRU)-UK was used for this study. The climate data, including maximum temperature, minimum temperature and precipitation, for the time period of 1962-2011 was used for assessing impacts on growth of *Pinus wallichiana*. The climate dataset was confined to the period 1962-2011 due to technical and other constraints. For ring-width (RW) measurement, increment cores were extracted using Presler's Increment Borer, following the methods as described by Ahmed (1984). Twenty trees of *Pinus wallichiana* were selected at random from different locations of the Division. The core samples were preserved in tubes and shifted for analysis to Annual Ring Measuring Laboratory (ARM Lab.), Pakistan Forest Institute, Peshawar.

The samples were air dried to avoid fungal infection. The air dried cores were glued into grooved iron mounts with transverse surface of the core upwards. The cores were surfaced using a razor blade and applying successively finer grades sand paper with orbital sander. The RW was measured using Digital Positio-meter with Microcomputer-based measuring system. For each tree 50 rings were measured. Besides RW, intra-ring early wood formation (IEWF) and intra-ring late wood formation (ILWF) were measured. Mean sensitivity (MS), response of trees to growth limiting factors, especially climatic factors, was computed as relative difference in width from one ring to the next by using the formula, as described by Fritts (1976) and Rolland (1993):

$$MS_x = \frac{1}{n-1}\sum_{t=1}^{n-1}\left|\frac{2(X_{t+1}-X_t)}{X_{t+1}+X_t}\right|$$

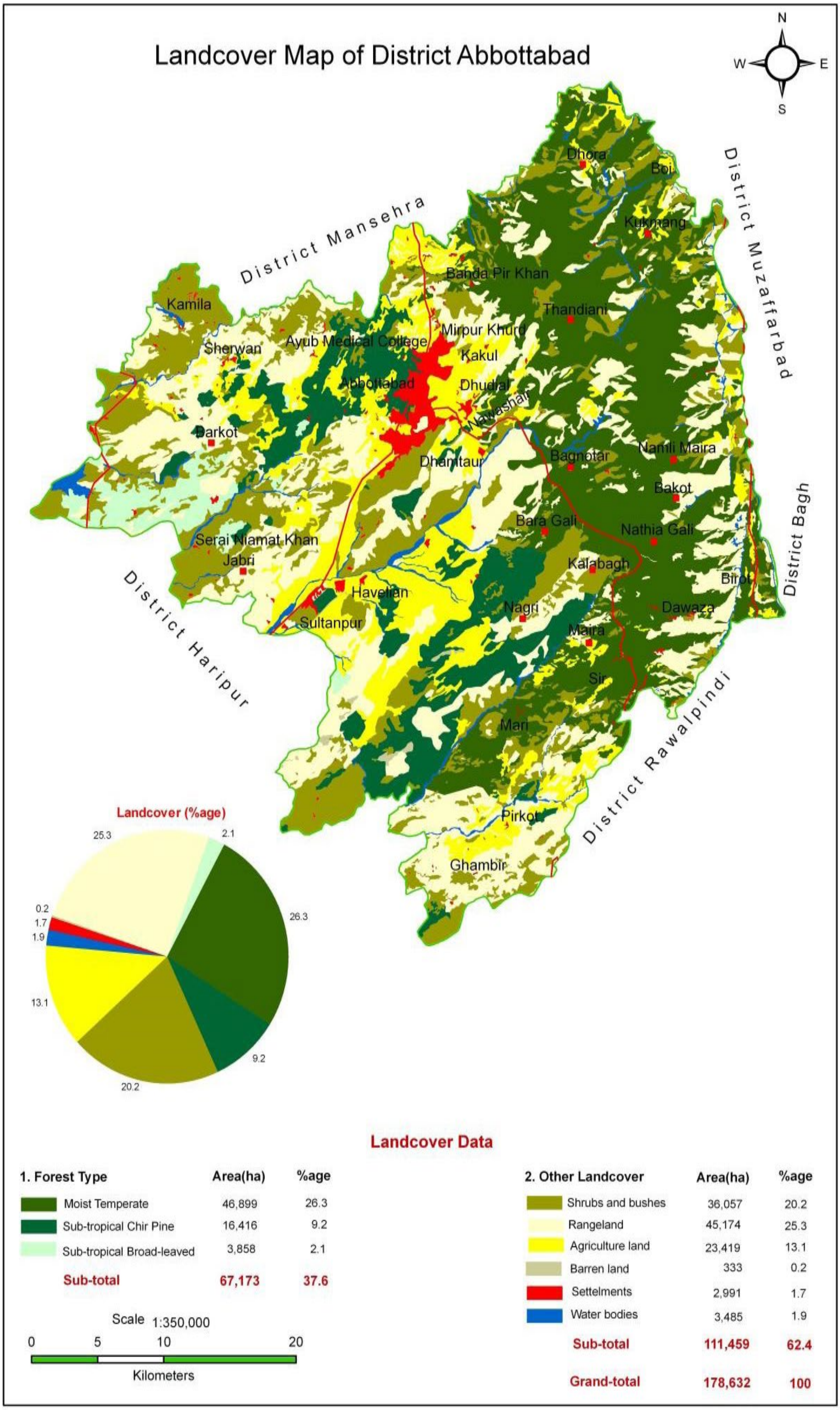

Figure 1: *Landcover map of Galies Forest Division- Abbottabad.*

Where;

MS_x = Mean sensitivity; X_t = Ring-width at year t; X_{t+1} = Ring-width at year t+1; n= Total number of rings.

The biological growth trend, decrease in RWs with increasing tree age - usually independent of other factors influencing tree growth, like climate, was removed by 'standardization' procedure (Fritts, 1976). Growth-climate response of *Pinus wallichiana* was assessed using standardized tree RW series and grid mean maximum temperature, minimum temperature and precipitation data by response function analysis.

The RW, IEWF and ILWF were analyzed using best fit regression analysis based on means of 20 trees. The significance of changes in the parameters was assessed applying analysis of variance test. Apart from regression analysis, decadal mean RW, intra-ring early and late wood was tested for significance using 1-Way analysis of variance. The significance among individual means was tested applying Tukey's Honest Significance Difference (HSD) test at p=0.05. The impact of climate change on the RW was assessed using Response function taking climate parameters as independent variable. The correlation between climate change and RWs was assessed using Pearson Correlation.

Results and Discussion

The mean sensitivity (MS) of RW was calculated to describe variability of high frequency component of the RW due to climatic fluctuations, while coefficient of variation (CV) was calculated for low frequency component variability induced either by climate or by other long term influences. The mean RW of *Pinus wallichiana* was measured as 2.54 mm, while the MS was 0.38. The coefficient of variation was found as 19.50 percent (Table 1). These results of MS and CV indicated enough variability for obtaining accurate growth results with correlation and response function methods.

Table 1: *Statistics of annual ring-width of Pinus wallichiana in GFD (1962-2011).*

Statistics	Estimate
Mean ring-width (mm)	2.54
Standard error (mm)	0.11
Mean sensitivity (MS)	0.38
Variance (σ^2) (mm)	0.25
Coefficient of variation (CV) (%)	19.50

The RW analysis indicated an overall decreasing trend in RW (Figure 2). The largest mean RW was 3.33±0.31 mm during 1962, while the smallest RW was 1.85±0.27 mm during 2002. The highest variability in RW across the cores of 20 trees was recorded in 1971. The time function growth response showed that RW, on average, remained higher and steady during 1960s which, conversely, decreased during 1978-86. The RW increased again during 1990s, followed by a considerable decrease during 2000-10. The RW was >3.0 mm during 13 years, and <2.0 mm during nine years.

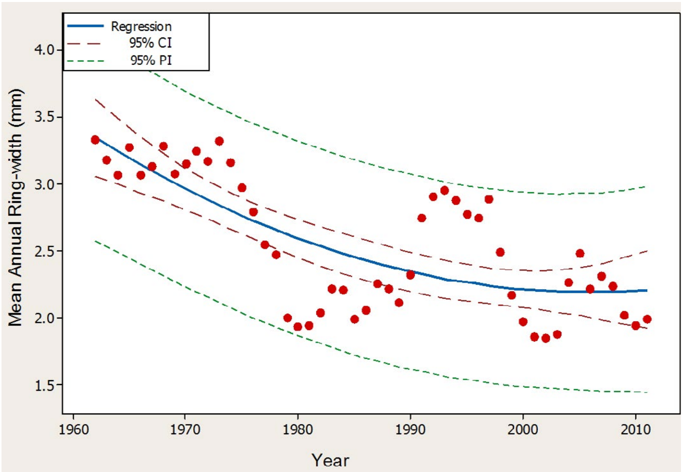

Figure 2: *Time function of ring-width of Blue pine in GFD (1962-2011).*

The analysis of time function response of IEWF within a ring showed a large variation. The mean IEWF within a growth ring was 75.56±0.21% (Figure 3). The results further showed an overall declining trend in IEWF. The largest IEWF was 78.87±1.51% during 1973, while the smallest was 72.12±1.80% during 2009. The IEWF followed a pattern similar to that of the RW, however, the slope of fluctuation was of lower degree in IEWF. The highest variability in IEWF across 20 cores was recorded in 1971. The IEWF increased slightly during 1970s and decreased during 1980s. The IEWF was >78.0% during nine years, and <73.0% during ten years.

The time function response of ILWF within a ring showed a considerable variation. The results showed an overall increasing trend in ILWF (Figure 4). The mean ILWF was 24.44±1.95%. The largest ILWF was 28.97±0.20% during 2002, while the smallest ILWF was 20.53±1.42% during 1976. The highest variability in ILWF across the 20 cores was recorded in 1998. The ILWF showed a curve of an opposite trend to that of IEWF. The ILWF increased steadily, except the slight declines during 1990s and 2005-08. The ILWF was >25.0% during 20 years, and <21.0% during two years.

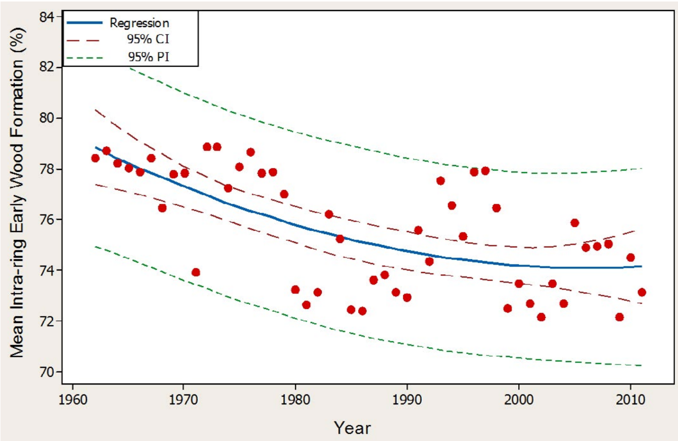

Figure 3: *Time function of intra-ring early wood formation (%) of Blue pine in GFD (1962-2011).*

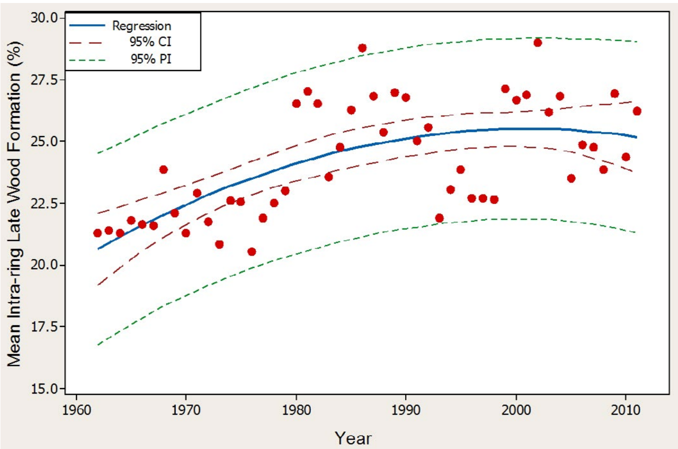

Figure 4: *Time function of intra-ring late wood formation (%) of Blue pine in GFD (1962-2011).*

Mathematical expression of RW and intra-ring wood formations showed quadratic behavior of time function (Table 2). The RW, IEWF and ILWF showed highly significant ($p<0.01$) changes with time. The R^2 ranged between 0.41 and 0.51. The highest R^2 value was calculated for RW, while the lowest R^2 value was calculated for the IEWF.

Table 2: *Mathematical expression of time function of ring-width and intra-ring wood formation of Blue pine in GFD (1962 to 2011).*

Climate parameter	Mathematical expression	R^2	$F_{2,47}$(p)
Ring-width	$Y=2421-2.412\times X-+0.0006\times X^2$	0.51	24.73 (0.000)
Intra-ring early wood formation	$Y=9697-9.591\times X-+0.0024\times X^2$	0.41	16.48 (0.000)
Intra-ring late wood formation	$Y=-12831+12.85\times X-0.003\times X^2$	0.42	16.89 (0.000)

An overall highly significant difference was observed in mean decadal RWs ($F_{4, 15}$= 272.25; $p<0.01$), with decreasing trend. The mean decadal RWs differed significantly (Tukey's HSD, CV 0.14; $p<0.05$) among themselves. The largest mean decadal RW was 3.40±0.04 mm during 1962-71, which was significantly ($p<0.05$) different from 1972-81. The difference in mean decadal RW between 1972-81 and 1982-91 was non-significant ($p>0.05$). The smallest mean decadal RW was 2.06±0.02 mm during 2002-11 (Table 3). An overall highly significant ($F_{4, 15}$= 16.9; $p<0.01$) difference was recorded in mean decadal IEWF. The mean decadal IEWF varied significantly among the decades (Tukey's HSD, CV 0.14; $p<0.05$). The largest mean decadal IEWF was 77.37±0.32% during 1962-71, which was significantly ($p<0.05$) larger, compared to mean IEWF during 1972-81. The smallest mean decadal IEWF was 73.63±0.53% during 2002-11. The difference in mean decadal IEWF among decades, 1982-91, 1992-2001, 2001-2011 was non-significant ($p>0.05$). The overall difference in mean decadal ILWF was highly significant ($F_{4, 15}$= 57.15; $p<0.01$). The ILWF varied significantly among the decades (Tukey's HSD, CV 1.02; $p<0.05$). The mean decadal ILWF increased with time. The largest mean decadal ILWF was 26.09±0.36 mm during 2002-2011, which was non-significantly ($p>0.05$) different from mean decadal ILWF during 1992-2001 (Table 3). The smallest mean decadal ILWF was 21.92±0.04 mm. The mean decadal ILWF during 1962-71 was significantly ($p<0.05$) lower compared to 1972-81.

Table 3: *Decadal changes in mean decadal ring-width and mean decadal intra-ring wood formation of Blue pine in GFD (1962-2011).*

Decade	Tree-ring characteristics		
	Ring-width ±SE (mm)	Early wood ±SE (%)	Late wood ±SE (%)
1962-71	3.40±0.04**a	77.37±0.32**a	21.92±0.04**d
1972-81	2.58± 0.03b	77.04±0.36ab	22.92±0.16c
1982-91	2.57± 0.04b	75.32±0.45bc	24.31±0.28b
1992-01	2.21± 0.03c	73.65±0.48c	25.65±0.20a
2002-11	2.06± 0.02d	73.63±0.53c	26.09±0.36a
CV	0.14	4.37	1.02

*** Highly significant (P<0.01); Mean values within a column sharing same alphabet (s) are non-significant (Tukey's HSD, p>0.05).*

Pearson correlation matrix revealed a highly significant ($p<0.01$) positive correlation (r = 0.80) between RW and IEWF. The correlation was highly significant ($p<0.01$) and negative ($r = -0.81$) between RW and ILWF. The correlation was highly significant ($p<0.01$) and negative ($r = -0.95$) between IEWF and ILWF (Table 4).

Table 4: *Correlation matrix between ring-width and ring-wood characteristics of Blue pine in GFD (1962-2011).*

Intra-ring Wood Formations	Ring-Width	Intra-ring Early Wood Formation
Intra-ring Early Wood Formation	0.80** (0.000)	
Intra-ring Late Wood Formation	-0.89** (0.000)	-0.91** (0.000)

*Values in ( ) are p-values; ** highly significant (p<0.01).*

Impact of climate change on RW was estimated using response function of RW with temperature (maximum and minimum) and precipitation. The RW showed a highly significant ($F_{1,48}$= 25.10; $p<0.01$) negative impact of increasing maximum temperature (Figure 5). Most of the RW response was observed between 16.0 - 17.0°C. The maximum temperature below 15.5°C showed a positive impact on RW, while maximum temperature above 17.0°C showed a negative impact on RW. The response analysis indicated that mean maximum temperature of 15.5°C and below was optimum for growth with the largest mean RW of 2.94±0.14 mm.

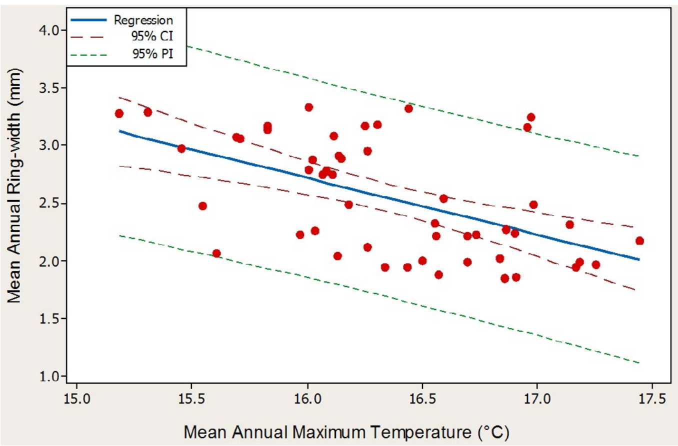

Figure 5: *Impact of maximum temperature on ring-width of Blue pine in GFD (1962-2011).*

The mean minimum temperature showed a highly significant ($F_{1,48}$=18.77; $p<0.01$) and negative impact on RW. The RW decreased with increasing minimum temperature (Figure 6). Relatively better growth response (RW >3.25 mm) was observed between 5.5 - 6.5°C. The minimum temperature below 6.5°C profoundly reduced the RW. These findings indicated that 5.5 - 6.5°C mean minimum temperature was optimum for growth of Blue pine.

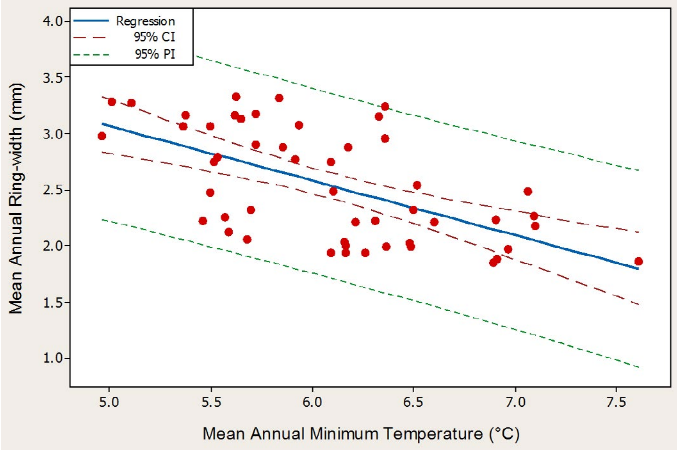

Figure 6: *Impact of minimum temperature on ring-width of Blue pine in GFD (1962-2011).*

The impacts of mean precipitation on RW was non-significant ($F_{1,48}$= 0.65; $p>0.05$). The mean precipitation of 800-1,000 mm/annum was relatively favorable for growth (RW >3.00 mm) of Blue pine. However, at this level of precipitation, irregular RWs were observed, showing a substantial variation in growth response (Figure 7).

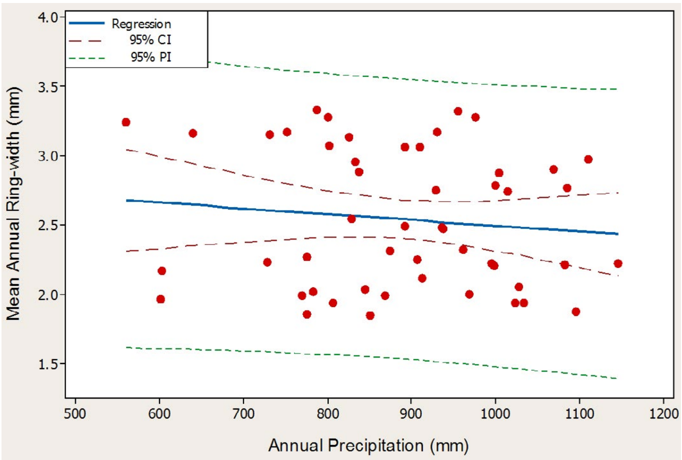

Figure 7: *Impact of precipitation on ring-width of Blue pine in GFD (1962-2011).*

The largest RW was 2.64±0.33 mm when precipitation was ranged between 600 - 700 mm/annum. The difference in the RW was marginal at precipitation of 601-700 mm/annum and 901-1000 mm/annum. The smallest RW was 2.41±0.13 mm when precipitation was > 1001 mm/annum (Table 5).

Mathematical expressions of impact of temperature and precipitation on RW showed linear functions (Table 6). The model for mean maximum temperature (R^2=0.34) showed a better fit compared to mean minimum temperature (R^2=0.28). The impact of mean maximum temperature and mean minimum temperature were highly significant ($P>0.01$) and mean precipitation was non-significant (P>0.05).

Table 5: *Precipitation and ring-width of Blue pine in GFD (1962-2011).*

Precipitation range (mm/annum)	Ring-width (mm)	SE
601-700	2.64	0.33
701-800	2.50	0.22
801-900	2.58	0.14
901-1000	2.60	0.12
>1001	2.41	0.13

Table 6: *Mathematical expression of impact of temperature and precipitation on ring-width of Blue pine in GFD (1962 to 2011).*

Climate parameter	Mathematical expression	R^2	$F_{1,48}$ (p)
Mean Max. Temperature	Y=5.500-0.486×X	0.34	25.10 (0.000)
Mean Min. Temperature	Y=10.57-0.49×X	0.28	18.77 (0.000)
Mean Precipitation	Y=2.913-0.0004×X	0.01	0.65 (0.425)

The present findings show a mean RW of 2.54±0.11 mm/annum of *Pinus wallichiana* during time period of 1962-2011. The mean sensitivity (MS) and coefficient of variation (CV) are 0.38 and 19.50%, respectively. The present MS of RW and CV indicate both high frequency component of the RW due to climatic fluctuations and low frequency component variability induced either by climate or by other long term influences, respectively. This MS value is broadly in agreement with MS values of 0.23 to 0.42 reported earlier by Ahmed et al. (2010) for *Picea smithiana*, *Cedrus deodara*, *Pinus gerardiana* and *Juniperus excelsa* in the Upper Indus Basin of Himalayan region of Pakistan. However, slight difference between present MS value and those reported by Ahmed and colleagues may be attributed to different tree species as well as study sites. Previously, such variations in MS values of different tree species and study sites have been reported by Bogino and Bravo (2009). The MS and CV values of *Pinus wallichiana* indicate a workable variability in RW for estimating accurate assessment of climate-growth response through application of correlation and response function methods as suggested earlier by Rolland (1993) and Speer (2010).

The present variations in RW demonstrated by the presence of several narrow and wide marker rings indicates a growth response of the species to climatic conditions. Previously, such corresponding narrow and wide marker rings in conifer species, as indicators of climate change, have been inferred by Khan et al. (2013) for *Cedrus deodara* in Chitral-Hindukush Range of Pakistan, and by Papadopoulos et al. (2009) for Aleppo pine in Attica Basin. The variations in RW and intra-ring wood formations are attributed to several factors. Some of these factors are unique to location of the tree, its age and management, while other factors are related to wider environmental factors, including temperature, rainfall and sunshine (Ahmed, 1984; Yeh and Wensel, 2000; Suarez et al., 2009). The present findings further reveal a negative and highly significant (P<0.01) impact of maximum temperature and minimum temperature on RW of *Pinus wallichiana*. The negative impact of increasing minimum temperature is found relatively greater compared to maximum temperature. Previously, similar negative impacts of maximum temperature and minimum temperature have been reported on RW of Scots pine (Bouriaud et al., 2005).

Besides RW, intra-ring wood formations also provide a promising tool for studying relationship between tree biology and climate change (Fonti et al., 2010). Intra-ring wood formations help to assess impacts of climate change and climate variability on tree growth and wood structure (Martinez-Meier et al., 2008; Hoffmann et al., 2011). Among the quantifiable intra-ring wood formations such as IEWF and ILWF are highly dependent on climate and facilitate more conclusive climate-growth relationship compared to total RW only (Rigling et al., 2003; Campelo et al., 2007; Vieira et al., 2009; Battipaglia et al., 2010; Lebourgeois et al., 2010). The present results are also in corroboration with the earlier reports.

The present results show mean IEWF of 75.56±0.21%, and mean ILWF of 24.44±1.95%. The IEWF decreases, while the ILWF increases with time. The changes in IEWF closely follow RW pattern. This relationship between RW and IEWF is the likely consequence that early wood constitutes a major part of RW (75.56±0.36%). Present results indicate also positive correlation between RW and IEWF. These findings are in corroboration with the results reported by Olano (2012) for *Juniperus thurifera*. Present change in ratio between IEWF and ILWF may affect significantly the wood quality. It is likely that the resin canals will occur in early wood and the transition from early wood to late wood will be gradual in case of larger early wood formation and vice versa. Such phenomenon was observed in Scots pine (Novak et al., 2013). Conversely, larger late wood portion enhances likelihood of L-ring formation. L-ring formation is related to summer stop and later restart with another growing cycle in autumn, if the conditions are favorable (Luis et al., 2011). These favorable conditions provide longer growing season and consequently increase in late wood quantity. The present increase in temperature vis-à-vis increase in ILWF indicates longer growth period and L-ring formation which may improve quality of wood of *Pinus wallichiana* in GFD. The complex relationship between RW and intra-ring wood formations suggests further that use of RW and intra-ring wood formations in combination can better interpret the climate-growth function compared to RW use alone.

Conclusions

Based on the results, it is concluded that RW of *Pinus wallichiana* showed a negative time function response. The decreasing RW with rising temperature and erratic fluctuations in precipitation indicated a negative impact of climate change on the growth *of Pinus wallichiana*. The IEWF exhibited a negative time function response. Contrarily, the ILWF showed a positive time response function. The rising minimum temperature showed a greater negative climate-growth response compared to maximum temperature. These results suggested that the use of ring-widths combined with intra-ring wood formations enables better assessment of impacts of climate change on tree growth.

Recommendations

Based on this study, it is recommended that:

1. Climate change estimates and scenarios may be made an integral part of Forest Management Plans, and future wood volume and yield estimates should be assessed in light of climate change scenarios.
2. The climate change trends in temperature and precipitation regimes and its seasonal variations may be used as guiding principles in adaption strategies for scientific forest management and other economic and socio-economic activities in the area.
3. Research studies may be conducted to promote new species and varieties with best adaption to emerging climatic conditions.

Author's Contribution

Syed Said Badshah Bukhari: Conducted the research as part of PhD. Planned and executed the experiments, drafted the manuscript.
Ghulam Ali Bajwa: Designed the experiments, analysed the data
S. Shafiqur Rehman: Supervised the research and corrected the manuscript.

References

Ahmed, M. 1984. Ecological and dendrochronological studies on Agathis Australis salisb-kauri. Ph.D. Thesis. New Zealand: Auckland Univ.

Ahmed, M., M. Wahab, N. Khan, M.U. Zafar and J. Palmer. 2010. Tree-ring chronologies from upper Indus basin of Karakorum range, Pakistan. Pak. J. Bot. 42: 295-207.

Baker, W. 1995. Long-term response of disturbance landscapes to human intervention and global change. Landscape Ecol. 10: 143-159. https://doi.org/10.1007/BF00133028

Battipaglia, G., D.V. Micco, W.A. Brand, P. Linke, G. Aronne, M. Saurer and P. Cherubini. 2010. Variations of vessel diameter and d13C in false rings of *Arbutus unedo* L. reflect different environmental conditions. New Phytol. 188: 1099-1112. https://doi.org/10.1111/j.1469-8137.2010.03443.x

Bogino, S. and F. Bravo. 2009. Climate and intra-annual density fluctuations in *Pinus pinaster* subsp. *mesogeenesis* in Spanish woodlands. Can. J. Res. 39: 1557-1565. https://doi.org/10.1139/X09-074

Bouriaud, O., J.M. Leban, D. Bert and C. Deleuze. 2005. Intra-annual variations in climate influence growth and wood density of Norway spruce. Tree Physiol. 25: 651-660. https://doi.org/10.1093/treephys/25.6.651

Bukhari, S.S.B. 2011. Participatory forestry management development trends in Pakistan. Paper presented at regional conference on participatory forest management: Bhopal, India.

Bukhari, S.S.B. and G.A. Bajwa. 2011. Climate change trends over coniferous forests of Pakistan. Pak. J. Forest. 61: 1-14.

Bukhari, S.S.B. and G.A. Bajwa. 2012. Development of National Response Strategy to Combat Impacts of Climate Change on Forest of Pakistan. Peshawar: Pak. Forest Inst. p: 156.

Campelo, F., C. Nabais, H. Freitas and E. Gutierrez. 2007. Climatic significance of tree ring-width and intra-annual density fluctuations in *Pinus pinea* from a dry Mediterranean area in Portugal. Ann. For. Sci. 64: 229-238. https://doi.org/10.1051/forest:2006107

Carter, K.K. 1996. Provenance tests as indicators of growth responses to climate change in 10 north temperate tree species. Can. J. For. Res. 26: 1089-1095. https://doi.org/10.1139/x26-120

Fonti, P., G. Von-Arx, I. Garcıa-Gonza´lez, B. Eilmann, U. Sass-Klasen, H. Gartner and D. Eckstein. 2010. Studying global change through investigation of the plastic responses of xylem anatomy in tree rings. New Phytol. 185: 42-53. https://doi.org/10.1111/j.1469-8137.2009.03030.x

Fowler, H.J. and D.R. Archer. 2006. Conflicting signals of climate change in the upper Indus Basin. J. Clim. 19: 4276-4293.

Fritts, H.C. 1976. Tree-Rings and Climate. Academic Press, London.

Hoffmann, W.A., R.E.M. Marchin, P. Abit and O.L. Lau. 2011. Hydraulic failure and tree dieback are associated with high wood density in a temperate forest under extreme drought. Glob. Change Biol. 17: 2731-2742. https://doi.org/10.1111/j.1365-2486.2011.02401.x

Khan, N., M. Ahmed and S.S. Shaukat. 2013. Climatic signal in tree-ring chronologies of *Cedrus deodara* from Chitral Hindukush range of Pakistan. *Pak. J. Bot.* 40(3): 1063-1070.

Lebourgeois, F., C. Rathgeber and E. Ulrich. 2010. Sensitivity of French temperate coniferous forest to climate variability and extreme events (*Abies alba*, *Picea abies* and *Pinus sylvestris*). J. Veg. Sci. 21: 364-376. https://doi.org/10.1111/j.1654-1103.2009.01148.x

Luis, M., K. Novak, J. Raventos, J. Gricar, P. Prislan and K. Cufar. 2011. Climate factors promoting intra-annual density fluctuations in Aleppo pine (*Pinus halepensis*) from semiarid sites. Dendrochron. 29: 163-169. https://doi.org/10.1016/j.dendro.2011.01.005

Martinez-Meier, A., L. Sanchez, M. Pastorino, L. Gallo and P. Rozenberg. 2008. What is hot in tree rings? The wood density of surviving Douglas-firs to the 2003 drought and heat wave. For. Ecol. Manage. 256: 837-843. https://doi.org/10.1016/j.foreco.2008.05.041

Novak, K., M.D. Luis, J. Ravento and K. Cufar. 2013. Climatic signals in tree ring-widths and wood structure of *Pinus halepensis* in contrasted environmental conditions. Trees. 27: 927-36. https://doi.org/10.1007/s00468-013-0845-5

Olano, J.M. 2012. Quantitative tracheid anatomy of *Juniperus thurifera* reveals a complex environmental control of wood structure under continental Mediterranean climate. Int. J. Plant Sci. 173: 137-149. https://doi.org/10.1086/663165

Papadopoulos, A., K. Tolika, A. Pantera and P. Maheras. 2009. Investigation of the annual variability of the aleppo pine tree-rings width: the relationships with the climatic conditions in the Attica basin. Glob. Nest. J. 11(4): 583-592.

Rigling, A., H. Bruhlhart, O.U. Braker, T. Forster and F.H. Schweingruber. 2003. Effect of irrigation on diameter growth and vertical resin duct production in *Pinus sylvestris L.* on dry sites in the central Alps, Switzerland. For. Ecol. Manage. 175: 285-296. https://doi.org/10.1016/S0378-1127(02)00136-6

Rolland, C. 1993. Tree-ring and climate relationships for *Abies alba* in the Internal Alps. Tree-Ring Bull. 53: 1-11.

Sheikh, M.M., N. Manzoor and M. Adnan. 2012. Precipitation related disasters in Pakistan, linkage to climate change, risk reduction and possible adaptation measures. Pp: 33-45. In: Proceed. 2nd Internat. Disaster Manag. Conf.: Good Governance in Disaster Risk Reduction and Clim. Change Adaptation.

Smith, J.B. and D.A. Tirpak. 1989. The potential Effects of Global Climate Change on the United States. EPA-230-05-89-054. Washington: U.S. Environ. Prot. Agency.

Speer, J.H., 2010. Fundamentals of Tree ring research, The University of Arizona Press Tucson.

Spurr, S.H. and B.V. Barnes. 1980. Forest Ecology, 3rd Ed. New York: John Wiley and Sons.

Suarez, G., C.J. Butler and M.G.L. Baillie. 2009. Climate signal in tree-ring chronologies in a temperate climate: Multi-species approach. Dendrochronologia. 27: 83-98.

Turner, M.G., W.L. Baker, C.J. Peterson and R.K. Peet. 1998. Factors influencing succession: Lessons from large, infrequent natural disturbances. Ecosyst. 1: 511-523. https://doi.org/10.1007/s100219900047

Vieira, J., F. Campelo and C. Nabais. 2009. Age-dependent responses of tree-ring growth and intra-annual density fluctuations of *Pinus pinaster* to Mediterranean climate. Trees Struct. Funct. 23: 257-265. https://doi.org/10.1007/s00468-008-0273-0

Wani, B.A., H. Shah and S. Khane. 2004. Forestry Statistics of Pakistan. Peshawar: Pak. For. Inst. p: 50.

Yeh, H.Y. and L.C. Wensel. 2000. The relationship between tree diameter growth and climate for coniferous species in northern California. Can. J. For. Res. 30: 1463-1471. https://doi.org/10.1139/x00-074