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# DENDROCLIMATIC INVESTIGATION IN PAKISTAN, USING *PICEA SMITHIANA* (WALL) BOISS., PRELIMINARY RESULTS

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**Abstract**

Dendroclimatic studies were carried out in *Picea smithiana* dominated forests of Chera and Naltar, located in Himalayan region of Pakistan. Six hundred year (1400-2006 AD) dated chronologies are presented. Each chronology obtained from highly correlated (0.65 to 0.73 correlation) wood samples. These chronologies were standardized using the program ARSTAN, so that long-term climatic trends could be detected. Various chronology statistics were discussed. Climate and growth response of *Picea smithiana* was analyzed using response function (RF) analysis. Overall response function analysis was highly significant, showed 37 to 40% variance due to climate. The results presented in this paper are encouraging for long term climatic reconstruction using this species. However more investigations are suggested to improve the results.

## Introduction

It is now widely accepted that the world's climate is changing (global warming) due to human activities. The urgent question is into what does this mean to Pakistan? Developed countries are spending billions of dollars each year to obtain information about the likely effects of climate change and supporting professional staff to identify the primary risks to their economy (such as forestry, agriculture, water-supply, hydroelectricity and pests and diseases). Every country wants to know what changes might happen to them so that they may prepare and / or adapt. However, a main limitation to being able to accurately model the future scenario is a lack of long or detailed information on past climate systems and their behavior. Consequently there has been a widespread international effect to find and use other reliable indicators. One of the best "tools" to provide this information has been tree-rings (the science of dendrochronology).

The prefix "dendro" is from the Greek word for tree and "chronology" is the area of science that deals with time and the assignment of dates to particular events. This science can be further divided into various sub-branches. The prefix dendro- is used with the name of particular scientific discipline, so dendroclimatology refers to the dendrochronological investigation of past climates. This is normally accomplished in a sequence of different phases:

1. Selection and sampling of suitable tree species at climatically sensitive sites.
2. Ring-width measurement, growth pattern matching and filtering to produce a standardized tree-ring sequence from a site (called a tree-ring chronology).
3. An evaluation of the sensitivity of the tree-ring chronology to particular climatic variables using a statistical analysis program (called response function analysis).
4. The strongest tree-ring–climate relationship from multiple different sites is then modeled (known as calibration and verification) and subsequently used to reconstruct the climate back in time before the climate records began (i.e. transfer function analysis). This last phase is beyond the scope of this paper.

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There has been limited previous dendrochronological research in Pakistan. The pioneering studies were by Ahmed (1987, 1988, 1989) and Ahmed & Sarangzai (1991, 1992). This was followed independently by Esper *et al.*, (1995) and Esper (2000). More recently, several other papers have occurred starting with Ahmed and Naqvi (2005), Treydte *et al.*, (2006), Khan *et al.*, (2008) and Ahmed *et al.*, (2009).

In this paper we are presenting preliminary results of the climatic response of *Picea smithiana* and this is the first investigation into this species for Pakistan. This study is a part of a research program aimed at developing reconstructions of past climatic conditions and the flow of the Indus River based on the tree-rings of various conifer species within Pakistan.

## Materials and Methods

Standard dendrochronological procedures (Ahmed, 1984; Norton & Ogden, 1987) were employed to collect, prepare and polish the wood samples for analyses. These samples were than visually cross-dated using a stereoscopic microscope. The growth rings of each sample were subsequently measured to the nearest 0.01 mm using a Velmex measuring stage linked to a computer. The data was then subjected to quality control assessment program COFECHA (Holmes, 1994) to check on the visual cross-dating. The tree-ring measurements were then passed through a standardization process, using program ARSTAN (Cook, 1985; Holmes, 1994). The primary purpose of the standardization process was to enable individual tree-ring series to be combined together to form a site chronology in an unbiased manner while retaining the climate signal.

**Response function (RF) analysis:** The climate dataset known as CRU TS 2.1 (http://www.cru.uea.ac.uk/) was used for the RF analysis. A database of monthly climate records from meteorological stations is used to construct a 0.5° gridded data for the period 1901-2002 (Mitchell & Jones, 2005). We selected the closest grid cell to the tree-ring sample sites for analysis.

After the standardization of ring-width data, the tree-ring series were subjected to response function analysis. The purpose of this analysis is to illustrate the quantitative relationship between species ring-widths and climatic variables, and to assess the potential of this species (from two Himalayan sites) for further investigation.

In the past, various techniques had been tried in order to obtain an understanding of tree-growth / climate relationships. Most methods considered only one limiting factor and calculated the simple correlation between a climatic factor and ring-width. This method was not satisfactory, due to the complex and inter-correlated nature of the climatic variable. Fritts (1976) introduced response function analysis (multiple regressions) to overcome these problems.

According to Hughes & Milson (1982), RF analysis does not measure the climate growth response, rather it only describes the nature of the climatic factors that influence the tree growth and also show the direction and strength of this relationship. Though some limitations of this technique were known to Fritts (1976) and pointed out by others such as Guiot *et al.*, (1982), Brett (1982) and Norton (1983), it has still been successfully used by numerous researchers thorough-out the world and is the only standard technique widely available. Consequently, the RF analysis technique was used to assess climate growth relationship of *Picea smithiana* in Pakistan.

RF analysis is a combination of principal components and multiple regression analysis. It is suggested that at least 42 predictors (climatic data) are required to perform a reliable RF analysis. The standardized tree-ring series are often highly auto-correlated. This is where there is a “memory” or persistent effect thought to be influencing growth in subsequent years. For example, exceptionally good climate for growth in one year may have a lingering effect on the trees growth in subsequent years. The level of this auto-correlation effect needs to be taken into consideration when evaluating the response strength of *P. smithiana* to climate. To overcome this problem it is suggested that, in addition to the climatic data, prior growth should also be considered as a predictor. For this reason lag years are included in the analysis at the level of the stepwise multiple regression. However, according to some experts, principal components should be truly independent and this method introduces an artificial loading and instability into the RF analysis. Consequently, prior growth years were introduced at the beginning, at the level of the monthly climatic data in the principal component analysis. Following Ahmed (1984) and Ogden & Ahmed (1989) a de-autocorrelation technique was applied, which removed most of the persistence in the ring width sequence.

The principal components are a set of uncorrelated (orthogonal) variable which are derived from the correlated climatic data set and are representative of the original data. Since climatic variables are inter-correlated, they are first converted (with lag years if used) into principal components (eigenvectors). The analysis then calculates the simple correlation coefficient for each variable with all other variables and selects only the most important components. These selected components reveal a large proportion of the variance while the other components show unimportant variation in the original data that may be due to noise or errors. In this way, there is a reduction in the number of components, increasing degrees of freedom and the small-scale variability and noise are removed by the elimination of the least important components.

The results of the climate principal components analysis are then subject to multiple regression, with summarized ring-width indices as the predicted. According to some experts since the climatic data are in uncorrelated form, applying step-wise multiple regression technique is unnecessary. Therefore only multiple regression analysis was performed to calculate the regression coefficients.

In the final step the principal components were transformed again into a new set of coefficient (the response function), portraying the relationship between ring-width and the original variables (i.e. correlated climatic data). Each coefficient was directly interpreted as the response to monthly temperature or rainfall with their 95% confidence limits. If the range of variability of the climatic factors (temperature or rainfall) is near the optimum for growth there is likely to be a significant positive effect on growth, while in the other case the correlation or response between climate and growth will be negative or insignificant. The overall significance of RF analysis was evaluated by the binomial test of Grey *et al*., (1981).

## Results and discussion

Table 1 shows the characteristics of the two tree sampling sites and both occur within the dry-temperate areas of Pakistan. Naltar is situated higher than Chera and facing snow-covered peaks. The situation of soil moisture at Naltar seems better than Chera due to melting snow and lies in the upper watershed area bordering sub-alpine vegetation and the timber-line. Naltar also supports the only known pure, abundant and large *P. smithiana* forest remaining in the country. Microscopic analysis of tree-ring samples from both sites showed cross-matching ring-width patterns with few partially missing or false rings.

A statistical summary from the COFECHA program from both sites is given in Table 1B. The cross-dated chronologies from both sites span in excess of 600 years. The Chera chronology shows higher statistical values for inter-series correlation (i.e. the trees are all responding together the same way), mean ring-width and mean sensitivity. A higher autocorrelation value was recorded from Naltar however subsequent processing was able to filter-out this effect and reduce the amount of autocorrelation considerably from both chronologies. It is evident that both sites contained some trees that are older than 600 years in age. These chronologies may be extended further back in time by searching and sampling older trees.

The summary of ARSTAN output statistics is presented in Table 1C. The mean sensitivity, autocorrelation and standard deviation are frequently used to assess the dendroclimatological quality of a tree-ring chronology. The first two statistics measures the proportion of high and low frequency variance respectively while standard deviation is a measure of variation in both frequency domains. The coefficients skew and kurtosis are included to assess any higher-order effects on the probability distribution owing to the method of standardization.

Figure 1 shows the number of samples that contributed to each year in the final two chronologies. In general, the sample size is considered satisfactory however there is the commonly observed problem of fewer and fewer trees being present as the chronology extends further back in time. This is especially evident at the Chera site. Therefore one suggestion is to recommend further sampling to increase sample replication before AD 1600. The same activity may also extend the chronologies further back in time.

The raw chronologies are also plotted in Fig. 1 and the bias caused by growth trends and the effects of age are obvious. From AD 1400 to 1800, the trees from Naltar showed fast growth, while during the same period slow growth in Chera might indicate that those trees had developed under a closed canopy, competing for light or nutrients. The gradual decrease in growth from 1800 AD is probably the effect of old age/increasing tree size. Both trends have been removed during standardization in the ARSTAN program.

Fig. 1 also shows the outcome of standardization. The final ARSTAN chronologies were created by reincorporating the pooled autoregression model into the residual chronologies. The pooled autoregression contains the persistence (climate + species physiology) and is retained while the remainder is removed (i.e. nonclimatic). Thus the intended outcome was a pair of chronologies containing the strongest climatic signal (Cook, 1985). These ARSTAN chronologies indicate that *Picea smithiana* from both sites, exhibit common growth trends within individual site, as shown by the high proportion of samples, that were able to be cross-dated. Such synchronous variation in ring-width can be caused by climate or by large-scale disturbance. Since it is shown that tree-ring patterns are similar with in *Picea smithiana* for both sites (i.e. spread over a wide geographic area), it is most likely that climate was the primary limiting environmental factor.

The climate and growth relationship was explored (Fig. 2). Only in extreme cases, such as a very stressed situation, do tree-rings respond to a single climate variable (temperature, rainfall etc) The general tree-climate relationship is so complex that the climatic signal can only be obtained from tree-ring data by sophisticated filtering and statistical techniques (Fritts, 1976) such as RF analysis. Climate is the predictor and variation in the tree-rings is the predictand. A time span of 18 months starting from prior May to current August is used for this analysis.

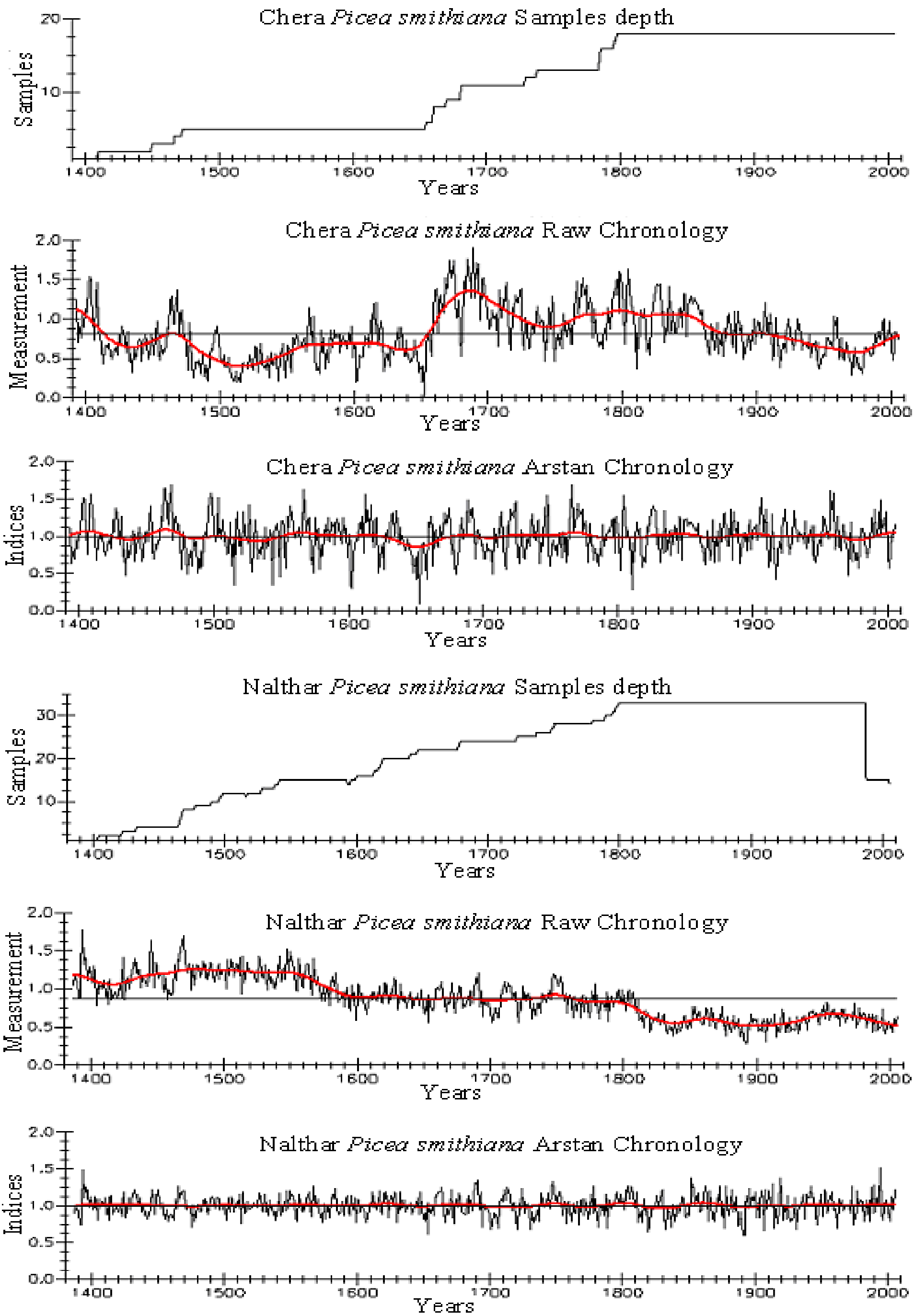


Fig.1. Comparison of Chera and Naltar tree-ring chronologies of *Picea smithiana*. First figure shows sample depth used to derive the chronologies. The second shows the raw series and the third the final filtered series (ARSTAN chronology).

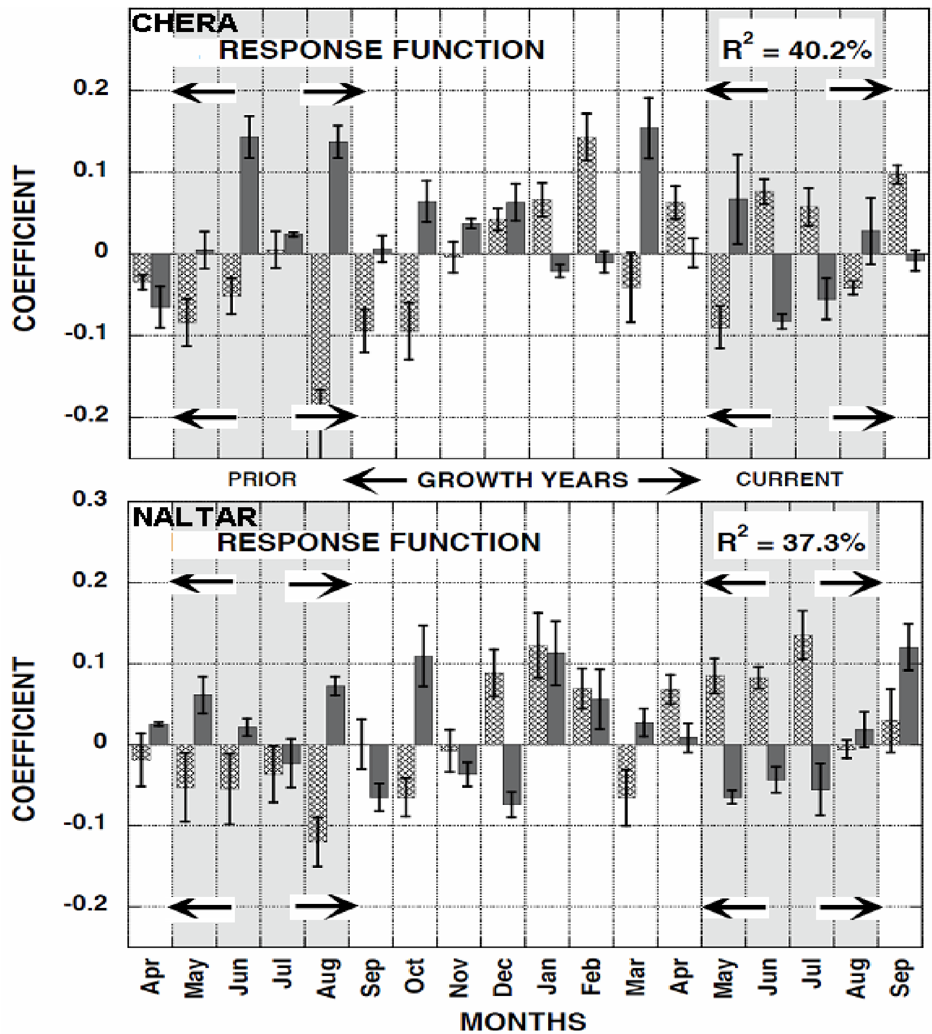


Fig. 2. Response Function Analysis of the two sites Chera and Naltar. Lines in the bar are the 95% confidence limits for each coefficient. Significant coefficients are those where the lines are completely above or below the zero line. Current and prior growth seasons are shown and divided into three periods. $R^2$ =Variance explained due to climate. Solid bars are precipitation, etched bars are temperature.

At Chera, there are 15 significant temperature coefficients of which 7 are positive and 8 are negative. Significant rainfall coefficients are 12 in which 7 are positive and 4 negative. From Nalter 13 significant temperature coefficients are obtained, 7 are positive and 6 negative. Significant rainfall coefficients are more than Chera (15) in which 8 showed positive while 6 showed negative response. The binomial test indicated that overall response function analysis was highly significant since more than 4 coefficients were non-zero at the 95% level (Fig. 2). The average correlation coefficient between all sequences ranged from $R^2$ = 37% (Nalter) to $R^{2\,=}$ 40% (Chera) is within the range of other studies of Ahmed (1984), Ogden & Ahmed (1989), and Xiong (1995).

**Table 1a. Sites characteristics of *Picea smithiana*.**

| Sites | [1]Lati N | [2]Long E | [3]Ele m | [4]Asp | Slope (0) |
|---|---|---|---|---|---|
| Gilgit Chera | 36 º 02` | 74 º 35 ` | 3100 | SW | 25 |
| Gilgit Naltar | 36 º 09 ` | 74 º 11 ` | 3400 | E | 37 |

Note: 1= Latitude, 2= Longitude, 3= Elevation (m), 4= Aspect,

**Table 1b. Summary statistics of Cofecha of *Picea smithiana*.**

| Sites | //------------- Unfiltered -------------\\ | | | | | //--- Filtered ---\\ | | | |
|---|---|---|---|---|---|---|---|---|---|
| | [1]Corr with master | [2]Mean msmt | [3]Max msmt | [4]Std dev | [5]Auto corr | [6]Mean sens | [7]Max value | [8]Std dev | [9]Auto corr |
| Chera | 0.727 | 0.96 | 7.32 | 0.505 | 0.789 | 0.278 | 1.59 | 0.318 | 0.2 |
| Naltar | 0.653 | 0.82 | 4.28 | 0.400 | 0.840 | 0.217 | 1.13 | 0.250 | -0.001 |

Note: 1= correlation with master chronology, 2= Mean ring width, 3= Maximum ring width, 4 and 8= Standard deviation, 5 and 9= Autocorrelation, 6= Mean sensitivity, 7= Maximum value.

**Table 1c. Summary of standardized chronologies Arstan Statistics of *Picea smithiana***

| Sites | [1]Ch. Sp | [2]Mean sens | [3]Std dev | [4]Skw | [5]Kurts | [6]Tr.Var | [7]Pa.Au.Cor | | |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Order 1 | Order 2 | Order 3 |
| Chera | 1394-2005 | 0.237 | 0.251 | -0.065 | 0.137 | -0.0047 | 0.39 | 0.10 | 0.02 |
| Naltar | 1387-2005 | 0.144 | 0.141 | 0.019 | 0.025 | 0.007 | 0.20 | 0.13 | 0.01 |

Note: 1= Chronology span, 2= Mean sensitivity, 3= Standard deviation, 4= Skewness, 5= Kurtosis, 6= Trend Variance, 7= Partial autocorrelation.

*Picea smithiana* from both sampling sites show high number of similar significant responses. Significant positive response of rainfall and temperature were almost same from both sampling sites however Chera show higher number of negative responses to temperature. Despite some differences that were most likely due to the site differences, both response functions show similar trends. Prior to June and August show significant negative response with temperature while rainfall shows significant positive response. Higher temperature in the two months is bad for growth since increased temperature would enhance transpiration resulting in a water shortage in the soil, while rainfall during these months reduced water deficit-hence good for plant growth. A similar response (significant negative temperature and positive rainfall) was also detected in October, March, April and only in Chera in May. Positive rainfall response at high elevation is not clear, especially in the winter season, however at Chera in May the significant negative temperature and positive rainfall response is easily explainable.

At Naltar, due to being at a higher elevation, the influence of melting snow and snow covered peaks shows a different response to Chera. In the month of May above average rainfall likely to drop the temperature, so it seems bad for growth while increased temperature enhanced the physiological activity in the plant, hence good for growth. This trend persists for the months of June, July and August. At higher elevation, rainfall not only reduces the sunshine period and photosynthesis, it also drops the temperature leading to reduced physiological activity, with the net result being reduced growth in trees. Therefore it seems reasonable that at higher elevations, even during the summer period, above average rainfall may reduce growth and the increased temperature in these months is favorable for growth. Zhang & Hebda (2004) and Peng *et al*., (2008) also demonstrated strong positive correlation with July temperature from high elevation. At Naltar, significant rainfall tended to be positive, but this effect was less clear. It is suggested that due to some unexplainable responses, more response function analysis should be carried out.

At present these interpretations should be regarded simply a guide to the climatic factors that influence tree growth and the direction and relative strength of the relationship until verified by further investigation, using independent data.

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