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Tree ring variability and climate response of Abies spectabilis along an elevation gradient in Mustang, Nepal

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Churia Conservation: Efforts and Challenges in Nepal

The Churia range (also called Siwaliks) rises steeply from the Terai plains and extends as a contiguous landscape from east to west. It is bordered by the Mahabharat range in the north and by the Terai in the south. The Churia is young and composed of unconsolidated loose materials originated from soft rocks such as mudstone, sandstone, silt stone and shale. Soils are mostly formed on sedimentary rocks with shallow and coarse textured soils. Steep slopes and weakly consolidation of different layers is prone to severe surface erosion. It is stretched in 36 districts of the country, and incorporates about 12.76% of the total area, where more than 15% of the total population of the country reside.

Despite with nearly 72.37% of the Churia under forest cover and rich in biodiversity, it is alarming and considered vulnerable to natural disasters such as landslides, erosions, flood and climate change impacts. Vulnerability of fragile ecosystem is further aggravated by numerous anthropogenic interventions such as settlement through encroachment, clearing of forests for cultivation, over exploitation of timber and other forest products through illegal logging, uncontrolled grazing , excavation and extraction of sand and gravel thereby rapidly changing the face of the region. It can be seen that around 6.5 million cubic metre of gravel, stone and sand are legally extracted every year from the region and the illegal extractions are expected to be twice as much. In addition, the water flowing from the Churia range usually brings an immense amount of debris and deposits them in the main river channels downstream. These deposited debris reduce the carrying capacity of the rivers, which causes riverbed rising, river bank cutting, flashfloods and desertification of agricultural lands, siltation of reservoirs and barrages, and breaching of roads and bridges usually causes loss of life and properties in Churia as well as downstream Terai.

Recent researches observed that rivers from Churia range have widened and shifted from their original course to a greater extent such as in the Koshi, Balan, Ratu, Lakhandehi, Bangeri Dudhaura and Mohana. There are many government, non-governmental and international organizations involved in Churia conservation namely Terai Arc Landscape (TAL) Project and Western Terai Landscape Complex Project (WTLCP), World Wildlife Fund (WWF), German Technical Cooperation (GTZ) of Germany, International Union for Conservation of Nature (IUCN), Cooperative for Assistance and Relief Everywhere (CARE)-Nepal and Department

For International Development (DFID). However, no desired objectives of soil and water conservation and natural resources management could yet be achieved because of their individualistic approach. The Government of Nepal (GoN) has promulgated necessary acts and regulations, strategies and plans in which an urgent need of Churia conservation is placed on the highest priority. In this regard, the Ministry of Forests and Soil Conservation (MoFSC) has been working on "President Chure Conservation Programme" since 2011. More than three years after its launch, the 'iconic' President Chure Conservation Programme became unable to address the issues to protect the fast denuding Chure and the inner Terai range. The MoFSC is leading and implementing this programme in 27 districts through its two departments namely Department of Forests and Department of Soil Conservation and Watershed Management. The lack of commitment from the political parties and their local representatives, lack of adequate support from the bureaucratic level and lack of performance-based analysis of the current status of the region are some challenges in the implementation aspect of the programme. Having realized such intricacy in addressing the challenges in Churia conservation, the GoN has recently established the President Chure Terai Madesh Conservation Committee under the Development Committee Act, 2013 to address the issues in integrated approach.

Environmental degradation in the Churia region is not only limited in the upstream areas rather it has created more severe disasters in the downstream areas of the Terai region as well. A good understanding and interaction between the people of upstream and downstream must be established to have the conservation and mitigation activities implemented. These might be achieved by forming community organizations and networking in the river system. Integrated watershed management could be optimal option to address the aforementioned issues through identified conservation activities implemented effectively and strong coordination among all the concerned stakeholders. Baseline survey of both the socio-economic and bio-physical situation need to be known before any conservation and development activities start in the region. The research, survey and study programmes are equally important in this regard since, in one hand, they provide references for monitoring, supervision and evaluation of the programme implementation while, on the other hand, they justify the priorities, significance and urgency of the conservation activities in a scientific way.

Tree ring variability and climate response of *Abies spectabilis* along an elevation gradient in Mustang, Nepal

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In mountainous areas including the Himalayas, tree lines are expected to advance to higher altitudes due to global climate change affecting the distribution and growth of plant species. This study aimed at identifying the tree ring variability of *Abies spectabilis* (D. Don) and its response to the climate along an elevation gradient in the high Himalayas of central Nepal. Tree core samples were collected from four sites in Mustang district. All sites were located in the same valley and exposed to similar weather conditions. Out of 232 samples collected from the sites, Titi lower (2700 m), Titi upper (2900 m), Pangukhark (3100 m) and Lete upper (3300 m), 44, 40, 39 and 41 series were successfully cross-dated and ring-width chronologies including 168, 79, 138 and 156 years previous to 2012 were developed, respectively. Statistically significant differences in average annual radial growth were noted among the four sites with the highest radial growth observed at mid-elevation sites. Chronological statistics based on residual chronologies for the common period revealed that *A. spectabilis* at the upper elevation site was more climate sensitive than at the other three sites. At the highest-elevation sites the correlation between pre-monsoon precipitation and tree growth was positive, and for the month of May this was statistically significant ($p < 0.05$). Moreover, spring temperature (March-June) was negatively correlated with precipitation and with tree growth at all sites, and at the upper elevation site (3300 m) the correlation was significant for March, April and May.

Key words: Climate change, Dendro-climatology, Himalayas, tree line species, tree growth

Growth response of trees to climatic variations can be studied through the measurement of annual rings of trees growing at a particular site where climate is a limiting factor. The principle of the limiting factor states that plant growth is controlled not by the total amount of resources available but by the scarcest resources (Fritts, 1976; Speer, 2010). At the margin of a species' natural distribution range climate is usually a limiting factor for growth and, therefore, climatic effects on tree growth increase when approaching the very margin of the natural distribution range (Fritts, 1976; Schweingruber, 1996). For trees at very high altitudes (at the tree line) and in very cold regions temperature during the growth season are limiting their growth and therefore their growth is frequently found to be temperature sensitive (Peng, 2008; Koerner and Paulsen, 2004).

The Himalaya region is considered one of the most sensitive and vulnerable natural environments of the world (NBS, 2002; MoE, 2010; NPC, 2010; WECS, 2002). Any changes in the climate of such regions are likely to have strong impact on their environment (ICIMOD, 2010; MoE, 2010 and 2011; NBS, 2002; WECS, 2002; WWF-Nepal, 2006). However, knowledge of climate change in the high altitude Himalayan region is very limited (Borgaonkar *et al.*, 2008; ICIMOD, 2010; WWF-Nepal, 2006). Glacier retreat has been taken as one of the indicators of Himalayan climate change in the form of rising temperatures (ICIMOD, 2010; MoE, 2010). Tree line advancement, change of vegetation structure and species composition at

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the tree line, and stand growth dynamics are some of the biological indicators of climate change. Moreover, tree rings of the woody vegetation, especially conifer species growing at tree line altitudes of the Himalaya region, can be used to detect the climate signals that are recorded in their annual growth rings (Braeuning, 2001; Schweingruber, 1996; Yadav *et al.*, 2004). At high altitudes the strong relationship between climate variables and tree rings can be expected to provide a good basis for dendro-climatic studies (Leal *et al.*, 2007). Hence, tree ring records of the high altitude Himalayan region can provide valuable insight regarding Himalayan climate change and its impact on the vegetation (Borgaonkar *et al.*, 2011).

Other than the climate observed at meteorological stations, the tree-ring variability can also be influenced by local factors such as altitude, species, tree size, site (soil, ground water), slope, and aspect, all of which may alter the effects of climatic change on tree growth (Leal *et al.*, 2007; Oberhuber, 2004; Urbinati *et al.*, 1997). For example, in mountainous areas the relationship between observed climate at a meteorological station and tree growth at a site located in the vicinity of the station may vary with elevation as the actual temperature and precipitation at the site vary along the altitudinal gradient. Generally a decrease of 0.6°C in temperature is expected on average for every 100 meter increase in elevation in alpine and sub-alpine regions (Mani, 1981). Previous studies have observed significant differences in climate-tree growth relationships along altitudinal gradients in Tibet and China (Chen *et al.*, 2011; Peng *et al.*, 2008; Wang *et al.*, 2005). To understand patterns found on the southern side of the Himalayan range it is equally important to examine the influence of climate on tree growth along altitudinal gradients in the Nepalese part of Himalaya.

The number of dendroclimatic studies in Nepal Himalaya is increasing at a considerable pace (Cook *et al.*, 2003; Sano *et al.*, 2005; Bhuju *et al.*, 2010; Chhetri and Thapa, 2010; Gaire *et al.*, 2011; Dawadi *et al.*, 2013; Thapa *et al.*, 2013). However, so far no studies have focused on examining climate-tree growth relationships along elevation gradients in the Nepal Himalaya despite the marked gradients characterizing this region. A long annual ring width series can be an important source of reliable historical information for high altitude regions (Esper, 2000; Yadav *et al.*, 1997), and therefore long-living woody species have a high potential for dendroclimatic studies. Among the several Himalayan conifers *A. spectabilis* (D. Don) has proved its dendroclimatic potential along the entire Himalayan range (Suzuki *et al.*, 1990; Bhattacharyya, 1992; Sano *et al.*, 2005; Gaire *et al.*, 2011; Yadav and Singh, 2002; Yadav *et al.*, 2004). *A. spectabilis* is a high altitude fir distributed from 2400 m to 4400 m and with a natural range extending from Myanmar in east to Afghanistan in west (Jackson, 1994; Stainton, 1972). Therefore, the objective of this study is to examine the relationship between tree ring variability of *A. spectabilis* and climate along an elevation gradient in the high altitude central Himalayas of Nepal.

Materials and methods

Study area

Mustang district was selected for this research study since it includes many high-altitude areas where trees grow at the extreme limits of their distribution and should thus offer appropriate sites for establishing climate-tree growth relationships (Schweingruber *et al.*, 1992; Schweingruber, 1989). The district is located in northern part of Nepal (Fig. 1) between two great Himalayan ranges, Annapurna Himalaya in the east and Dhaulagiri in the west.
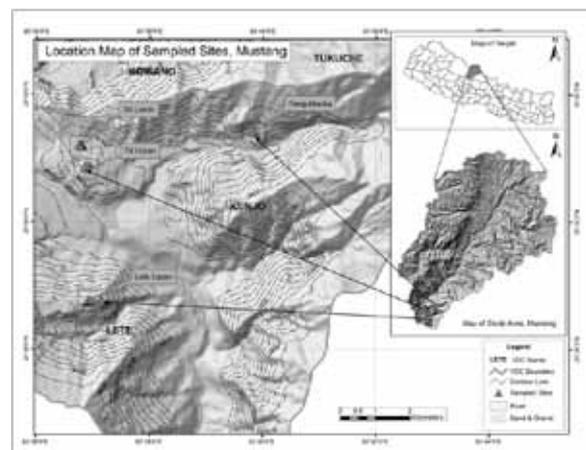

Fig. 1: Map of study area with sampled sites

The district includes large rain shadow areas with less than 200 mm rainfall annually, maximum temperature of 26ºC in the summer and minimum temperature of -20ºC in the winter (NTNC, 2008). In fact the majority of the district's area is located in the Trans-Himalayan region where a cold desert type with semi-arid climate prevails.

However, these areas are too dry for *A. spectabilis* and the study sites are therefore located in the southern part of the district (Lete and Kunjo VDCs), which receives more rainfall (more than 1200 mm annually) and where trees and forests of conifer species are distributed across a wide elevation range. Lete and Kunjo VDC of the Mustang district were characterized by long term research area (2003–2014) under the Community based Forest Management in the Himalayas (ComForM III) Project with the establishment of 12 permanent sample plots for biophysical and socio-economic survey (Meilby *et al.*, 2006). Only 3.24% of the total area is covered by forest and most of this forest is located in the southern part of the district around our sample sites. The forests are dominated by pine and fir in the cold temperate climatic zone, and high altitude conifer forests including *A. spectabilis* are found at different elevations. The natural resources of the areas are managed by the Annapurna Conservation Area Project (ACAP) since 1992 under the National Trust for Nature Conservation, a national non-governmental organization (www.ntnc.org.np).

Sampling design and sample collection

Study sites were established at four different elevations ranging from the lowermost margin of the distribution of *A. spectabilis* at around 2700 m up to 3300 m elevation at the mountain ridge. Each site was identified in such a way that the site homogeneity could be maintained as suggested by Schweingruber *et al.* (1992). For this purpose, a strip of land with a width of 50 m was established across the slope direction at intervals of 200 m along the slope. Tree cores were collected at a height of 1.3 m above ground using stainless steel Swedish Increment borers of three different sizes (24", 18" and 16" long and 5 mm thick). Descriptive details of the sampling sites and the number of samples collected are presented in table 1.

The sites were located within the same valley and it is therefore assumed that all four sites are exposed to almost similar weather conditions and climatic variations from year to year. Moreover, the major forest types in all sample sites were conifer-dominated, but the dominant conifer species varied between sites. Thus, the lower elevation sites (Titi lower and Titi upper) were dominated by *Tsuga dumosa*, whereas the upper elevation sites (Pangu and Lete upper) were mostly dominated by *A. spectabilis*.

Sample preparation and chronology development

Sample preparation was carried out following the standard method of tree ring analysis suggested by Cook and Kairiukstis (1992); Fritts (1976) and Schweingruber (1996). Collected samples were air dried, mounted in wooden frames and polished using sanding papers of different grit size (80, 120, 240, 400 and 600) until the ring boundaries were visible under microscope.

Ring widths were measured using TSAP-Win software attached to a LINTAB measuring system (version 5) operating at 0.01 mm resolution. The calendar year of each ring was assigned by matching the ring-width patterns of the samples of each site in TSAP-Win. The program COFECHA was used to check the accuracy of measurements and dating (Holmes, 1983). Successfully cross-dated samples were used for developing a ring-width chronology for each of the four sites located at different elevations (Table 1). Raw chronology, standard chronology, residual chronology and arstan chronology were developed using the ARSTAN computer program (Cook, 1985). The residual chronology was used for dendro-climatic analysis. This chronology was obtained after removing autocorrelation from the standard chronology by using autoregressive (AR) modelling. To obtain the standard ring-

Table 1: Description of sampling sites and number of samples

Sampled sites	Elevation range of sampled sites (m)	Middle elevation of sampled sites (m)	Latitude (northern)	Longitude (eastern)	Aspect	Sampled trees/cores
Titi lower	2675–2725	2700	28.653217°	83.611113°	North	30/57
Titi upper	2875–2925	2900	28.648258°	83.612645°	North	29/50
Pangu khark	3075–3125	3100	28.657358°	83.661236°	SW	30/58
Lete upper	3275–3325	3300	28.612734°	83.613277°	Ridge	36/67

width chronology, natural growth trends in the tree rings that are caused by factors other than climate were removed by fitting 30 year cubic smoothing splines to each of the ring width series.

Chronology characteristics were describedby estimating various statistics, including average ring width, standard deviation, mean sensitivity and autocorrelation for the entire period among all cross-dated tree ring series.The average ring width is a robust mean which was estimated by first averaging raw chronology ring widths for each tree and then averaging the individual tree averages, thus assigning equal weights to all sampled trees. These were also estimated for the common period and, in addition, correlations of ring width within each tree, between trees and among all series were determined for the common period. Signal to Noise Ratio, expressed population signal and variability 'explained' were also estimated for the common period.

Climate of the study area

Temperature and precipitation data from local meteorological stations, common to all sample sites, were used for analysis of the climate-tree growth relationship. There are three meteorological stations in the vicinity of the sites. The stations are located in Lete, Thakmarpha and Jomsom in Mustang district. Among these, the Lete station is closest to all sample sites and located within a distance of less than 5 km. Table 2 provides details on the three meteorological stations.

Temperature data from the station in Lete are limited to 1998–2012 which is insufficient for this study and, therefore, the Jomsom temperature data were applied for the climate-tree growth analysis. The correlation between the temperature data of Lete and Jomsom was found highly significant ($p<0.01$). Precipitation data of the Lete station covered the period 1969–2012 and were found sufficient for further analysis. Figure 2 depicts the monthly distribution of temperature and precipitation in the study site.
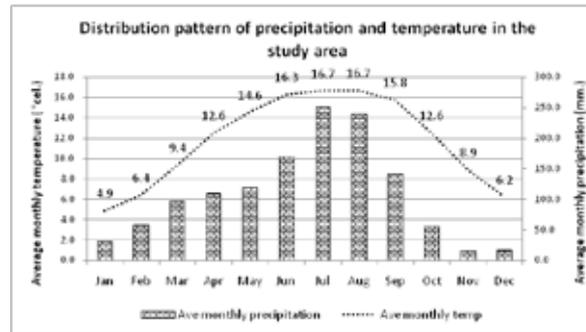

Fig. 2: Monthly distribution of precipitation and variation of temperature in the study area

Climate-growth relationship

The response of tree rings to climate fluctuations was analyzed using Pearson correlation coefficients. Correlations of the residual chronology with temperature and precipitation in different months were calculated for all sample sites with the help of the statistical software package SPSS.

Results and discussion

Out of the total set of collected samples, 44, 40, 39 and 41 tree ring series from Titi lower, Titi upper, Pangukhark and Lete upper sites, respectively, were successfully cross-dated. Samples that were broken during handling and those that were difficult to date were discarded. Table 3 shows descriptive information on radial growth of *A. spectabilis* at the four sites at different elevations. The robust average of tree ring width of *A. spectabilis* was found to be higher at the two sites in the middle of the elevation range (Titi upper and Pangu Khark) than at the other two sites at the ends of the elevation range. At the site at 3300 m elevation the average ring width was just about 1.54 mm. Average annual radial increment was about 5% at the 'Titi upper' site where the average annual rate of change in increment was only about -1.9%. The annual rate of change in radial growth was found to be smallest (-0.3%) at the site of highest elevation (3300 m), presumably

Table 2: Meteorological stations in Mustang district

Meteorological stations	Elevation (m)	Latitude (deg/min)	Longitude (deg/min)	Span of precipitation data (years)	Span of temperature data (years)
Lete, Mustang	2384	28.38°	83.36°	1969 – 2012 = 43	1998 – 2012 = 14
Marpha, Mustang	2566	28.45°	83.42°	1967 – 2012 = 45	1969 – 2012 = 43
Jomsom, Mustang	2754	28.47°	83.42°	1957 – 2012 = 55	1959 – 2012 = 53

Table 3: Descriptive information on ring width of *A. spectabilis* by elevation

Sample sites (m)	N	Ring width (mm)				Mean annual radial increment (%)	Mean annual rate of change of increment (%)
		Min	Max	Ave	Std.		
2700	44	1.06	3.45	2.07	1.11	2.22	-2.52
2900	40	1.25	3.62	2.27	1.23	5.03	-1.95
3100	39	1.18	4.16	2.21	1.01	2.75	-2.62
3300	41	0.81	2.68	1.70	0.85	2.74	-0.29

reflecting the relatively low average annual radial increment (2.7%) and the long span of years covered by many series at this site. Differences in average ring width along the elevation gradient were statistically significant (ANOVA, p<0.001). Hence climatic conditions, possibly including low temperature, associated with high elevations might be limiting the growth of the trees at the high-elevation site (3300 m) to a greater extent than at lower elevation sites.

Statistical information on the ring width chronologies prepared for *A. spectabilis* at the four different sites (elevations) is shown in table 4. Based on the common period the mean sensitivity of the residual chronology was higher at the upper elevation site (3300 m) and lowest in lower elevation sites (2700 and

2900 m). However, the pattern of variation of mean sensitivity along the elevation gradient was found to be reversed for the overall period of the tree ring series. The reason for this presumably is that for three sites (2700, 3100 and 3300 m elevation) about half of the span of years covered by the chronologies were based on very few samples (<5 sample trees) leading to high fluctuation in the ring width data and presumably inflating the mean sensitivity statistic. Nevertheless, this sort of pattern was also noticed in parts of China and Europe (Dittmar *et al.*, 2012; Cai and Liu, 2013; Liu *et al.*, 2013). The variation of the mean sensitivity was found highly significant (ANOVA, p<0.001).

The standard deviations of the tree ring chronologies (common period) followed a

Table 4: Statistics of ring width chronologies of *A. spectabilis* in four elevation sites

Statistics	Elevation sites (m)			
	2700	2900	3100	3300
Overall period	**1845 – 2012**	**1934 – 2012**	**1875 – 2012**	**1857 – 2012**
Tree/Series	26/44	23/40	26/39	26/41
MS	0.248	0.172	0.140	0.156
SD	0.248	0.177	0.139	0.151
AC/SC	0.113	0.166	-0.002	0.102
Common period	**1961 – 2012**	**1964 – 2009**	**1961 – 2010**	**1941 – 2012**
MS	0.209	0.205	0.209	0.227
SD	0.196	0.165	0.189	0.216
AC/SC	0.080	-0.175	-0.014	0.020
Ra	0.371	0.231	0.235	0.283
Rb	0.365	0.224	0.233	0.279
Rw	0.631	0.572	0.310	0.508
SNR	24.140	11.740	11.340	13.830
EPS	0.960	0.922	0.919	0.933
Var. explained	0.397	0.276	0.289	0.340

Note: MS: Mean sensitivity; SD: Standard deviation; AC/SC: Autocorrelation/Serial correlation; Ra: Correlation among all series; Rb: Correlation between trees; Rw: correlation within trees; SNR; signal to noise ratio; EPS: Expressed population signal.

similar trend along the elevation gradient as the mean sensitivity, i.e. the highest value was found at the upper elevation site (3300 m) and the lowest value at one of the lower elevation sites (2900 m). The first order auto-correlation varied greatly between sites. Higher absolute levels of auto-correlation were observed at the

lower elevation sites (2700 and 2900 m) and lower levels were found at upper elevation sites (3100 m and 3300 m). The mean values of MS, SD and AC for the common periods in standard chronology were different and the variation of these statistics was highly significant among the four sites (ANOVA; $p < 0.001$ for all values). The
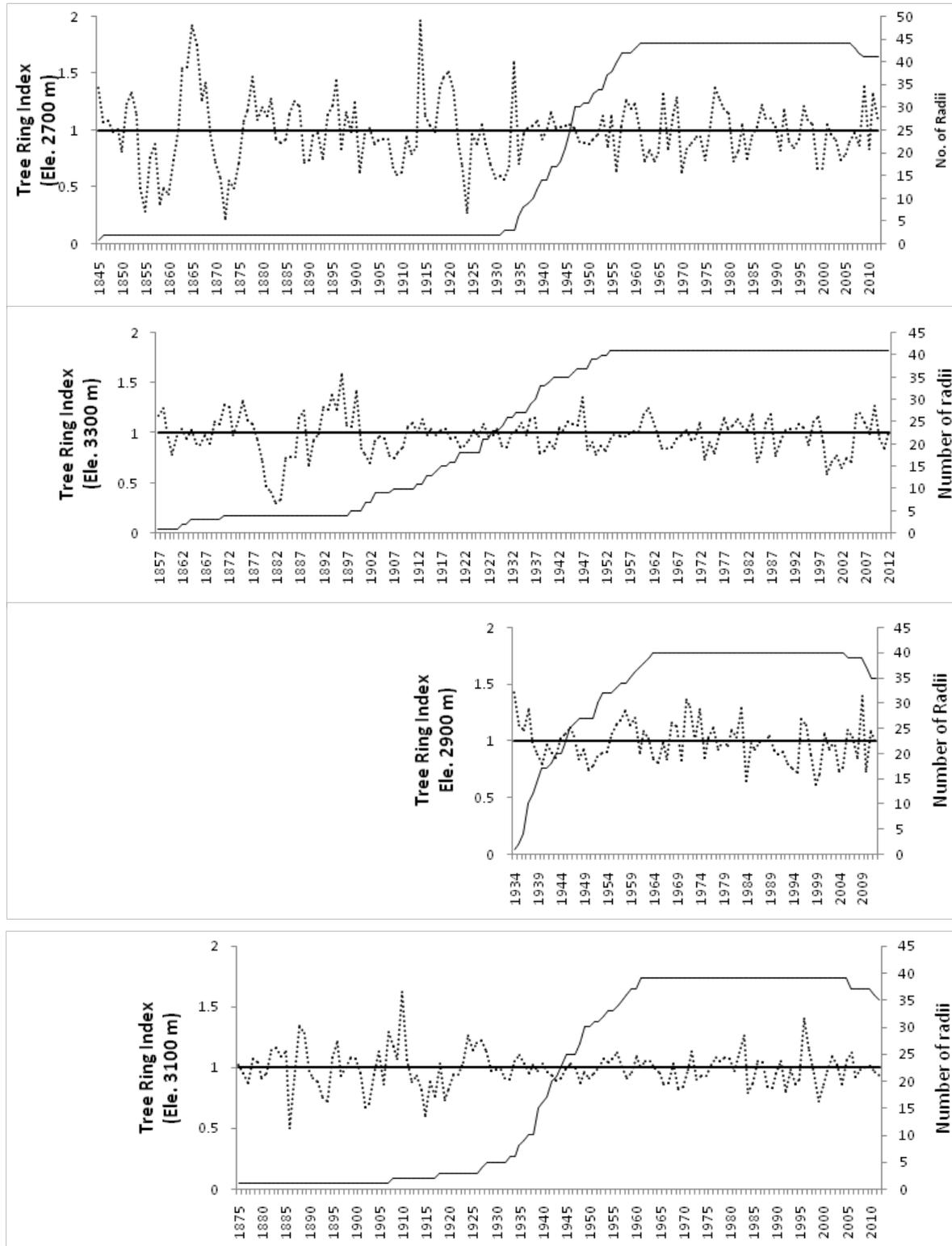
Fig. 2: Ring-width chronology of *A. spectabilis* in four sites along an elevation gradient in Mustang

values of MS and SD observed for the common period indicate that trees at higher elevation sites are slightly more sensitive to the climate than trees at lower elevation.

Correlation coefficients of ring-widths among all trees and between trees were slightly higher at 2700 m (~ 0.37) than at the other three sites (~ 0.22–0.28). The correlation coefficient within tree was high and similar at three sites (~ 0.50–0.63) but comparatively lower (~ 0.31) at the 3100 m elevation site. Similar correlation coefficients have been reported in other tree ring studies from the Himalaya region (Sano *et al.*, 2005; Bhuju *et al.*, 2010; Chhetri and Thapa; 2010; Gaire *et al.*, 2011; Dawadi *et al.*, 2013; Thapa *et al.*, 2013). The Expressed Population Signal (EPS) of the chronologies of all four sites exceeded the suggested threshold limit of EPS = 0.85, indicating that the chronologies developed from the available sample size represented the site chronologies of the respective elevations well (Wigley *et al.*, 1984). Figure 3 depicts the distribution pattern of standard chronology in four elevation sites in the study area.

Climate-tree growth relationship

A positive relationship was observed between tree growth and May precipitation in all elevation sites in the study area (Fig. 3), but the relationship was statistically significant only at 3100 m (p=0.007) and 3300 m (p=0.011) elevation. Similarly, correlation between tree growth and March precipitation was also positive in three elevation sites except 3300 m, whereas in April, positive association was only noticed in upper most elevation site (3300 m). In most of the previous studies in Nepal and India Himalaya, pre-monsoon precipitation was also found to influence radial growth of the species positively and significantly (Sano *et al.*, 2005; Chhetri and Thapa, 2010; Gaire *et al.*, 2011; Dawadi *et al.*, 2013; Thapa *et al.*, 2013; Borgaonkar *et al.*, 1999; Pant *et al.*, 2000; Yadav and Singh, 2002; Yadav *et al.*, 2004; Borgaonkar *et al.*, 2011; Ahmed *et al.*, 2011). Figure 4 further reveals that the ring-width showed a clear negative relationship with the precipitation of the June and July for all sites but no such clear and strong association were observed during the end of Monsoon. The precipitation signal was captured more strongly at the higher elevation site (3300 m) than at lower elevations (both positive and negative effects).

However, with regard to winter precipitation the relationships were weak and varied between sites. This indicates that the winter precipitation does not influence tree growth much in our study area. Precipitation values of the October, November and December were considered from the previous year whereas rest of the precipitation values were taken from the running year.
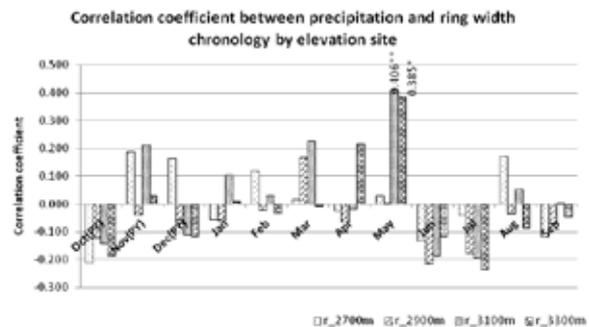
Note: * = significant at the 5% level; ** = significant at the 1% level; PY=Previous Year

Fig. 4: Relationship between monthly precipitation and tree growth by elevation site

Figure 5 shows the relationship between temperature and tree growth in the study area. Spring and summer temperatures (March, April, May and June) were negatively correlated with tree growth at all sites. However, the relationship was only significant (p<0.05) in three months of the pre-monsoon period (March-May) for the upper elevation site (3300 m) and in one month (April) for lower-elevation sites (2700–2900 m). In the late summer (August) the correlation between growth and temperature was only significant at the lower boundary of the species distribution (2700 m).
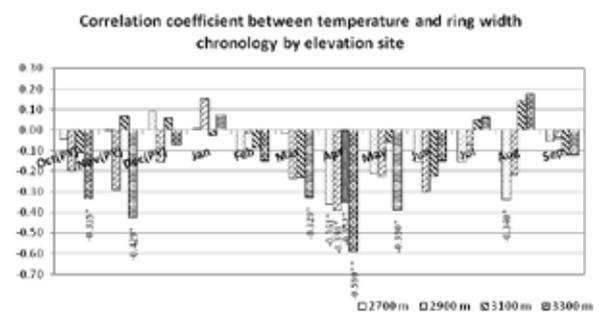

Fig. 5: Relationship between temperature and tree growth by elevation sites
Note: * = significant at the 5% level; ** = significant at the 1% level; PY=Previous Year

Pre-monsoon temperature was also found to be negatively correlated with growth of trees in other parts of the Himalayan range (Sano *et al.*, 2005; Chhetri and Thapa, 2010; Gaire *et al.*,

2011, Dawadi *et al.*, 2013; Thapa *et al.*, 2013; Borgaonkar *et al.*, 1999; Pant *et al.*, 2000; Yadav *et al.*, 2004; Borgaonkar *et al.*, 2011; Ahmed *et al.*, 2011).
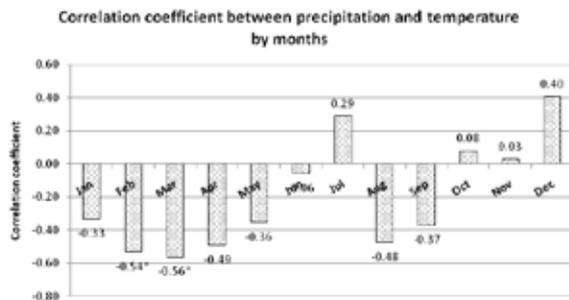

Fig. 6: Correlation between monthly precipitation and average monthly temperature

Note: * = significant at the 5% level, ** = significant at the 1% level

The only cases where temperature was positively but non-significantly correlated with growth were in the mid-winter (January) and mid-rainy seasons (July and August). Immediately this may appear peculiar, in as much as we would expect high-altitude trees to respond positively to higher temperatures, particularly if higher temperatures are experienced in spring or late autumn and would therefore seem to lead to extension of the growth season of the trees. However, a possible (partial) reason for the observed pattern is that temperature is correlated with precipitation. Therefore correlations between monthly precipitation and average temperature are explored in figure 6. It appears that correlations between monthly average temperature and monthly precipitation are generally negative before and after the monsoon but only significant for the months of February and March, implying that warm conditions are also comparatively dry conditions. This pattern is observed throughout the pre-monsoon season in the study area and the fact that trees appear to be responding negatively to temperature and positively to precipitation in the pre-monsoon period thus seems to indicate that growth is limited by water availability rather than temperature, at least in the pre-monsoon period.

Conclusion

In the study area in Mustang the lower and upper boundaries of the species distribution were characterized by lower radial growth rate compared to the mid-range of the species' distribution. The annual rate of change in radial growth was found to be smallest at the upper elevation site (3300 m). Trees at the upper boundary of the species distribution were more sensitive to the climatic conditions than trees at lower elevation sites (based on the common period of the residual chronology). The correlations between precipitation and growth were in most cases low, and while pre-monsoon correlations were positive for higher elevation sites, they were only significant in May, and only at the two highest-level sites. Spring and summer temperature had negative correlation with the tree growth in all elevation sites. Negative correlation between precipitation and temperature of the pre-monsoon season revealed that at this time of the year the precipitation is the main limiting factor for tree growth in all elevation sites.

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