ENVIRONMENTAL RECONSTRUCTION AND IMPACT OF CLIMATE CHANGE ON VEGETATION AT TREELINES OF NEPAL HIMALAYA

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SUMMARY

A study was undertaken to assess the upward shift of plant species and prepare a baseline on biotic inventories in Nepal Himalaya. The study was conducted between November 2013 and October 2014. Field surveys were conducted in three protected areas: Kanchenjungha (east), Rara (west), and Api-Nampa (far-west). In each site, tree-line and species limits were recorded and belt transects laid for sampling. With a focus on *Abies spectabilis* and *Betula utilis*, their height and diameter were measured and position noted. A total of 717 tree-cores of five species, viz. *A. spectabilis*, *B. utilis*, *Cedrus deodara*, *Picea smithiana*, and *Tsuga dumosa* were collected. Laboratory examination of tree-cores was done at NAST Dendro-Lab. The tree-line species composition was almost similar, having *A. spectabilis* and *B. utilis* in all three study sites. The tree-line position decreased from east to west Nepal; in the east, *A. spectabilis* was found at 4118 m, in the west at 3870 m. Preliminary results showed that this species was shifting upward at 2.4 m/yr. The oldest tree recorded was *T. dumosa* of 357 years in Api-Nampa. Tree-ring growth presented a negative relation with pre-monsoon temperature, but positive with precipitation of the same season. Based on the study, three MSc thesis and a paper for PhD are under preparation. Before the inception of the research, a training-workshop was organized on dendrochronology enhancing the research capability of the young generation.

INTRODUCTION

The rate of temperature increment in the Himalaya is reportedly high and its impacts are expected to be much evident at tree-line. However, there is a lack of empirical study and baseline data, for which IPCC (2007) has termed the region "white spot". In Nepal, climatic records provide evidence of an ongoing climate warming at the rate of 0.06°C per year with more pronounced effects in the high altitude regions. However, biotic inventories of many key sites are lacking, and loss or gain and/or changes in species abundance is hardly studied. Recently performed few dendro-ecological studies reported upward range extension of key plant taxa of tree-line ecotone at the faster rate, particularly of *Abies spectabilis* shifting upslope at 1.5 to 3.4 m/yr (Gaire et al 2014). Since tree-line determines the lower boundary limits of the alpine belt, an upward shift of the tree-line will restrict the overall alpine area and impacts the distribution of alpine species. This observed upward migration of tree species may provide some fundamental insight in assessing the climate change scenario in the Himalaya.

Many dendro-ecological studies have documented that trees at tree-line often respond to climatic warming with increases in recruitment as well as upward advances in the tree-line (Bradley & Jones 1993, Kullman 2002, Camarero & Gutiérrez 2004). Upward migration of tree-line has been reported ranging from 0.12m/yr to 5.7m/yr in different regions of the globe. Past studies on tree-ring indicated several species including *A. spectabilis, Betula utilis, Picea smithiana, Tsuga dumosa* from Nepal and India Himalaya are promising for dendroclimatological study (Bhattacharyya et al. 1992; Cook et al. 2003, Yadav et al 2004, Sano et al. 2005). Recently, researchers have carried out dendroclimatological and dendroecological studies covering different parts of high altitude of Nepal Himalaya (e.g. Dhakal 2008, Udas 2009, Bhuju et al 2010, Gaire et al 2011, Thapa et al 2013, Kharal et al 2014). In the high altitude of Nepal, the climate change impacts are expected to be more pronounced.

OBJECTIVES

The objectives of the study were:

1. To conduct an ecological survey and collect ecological data such as dbh, height, seedling, sapling number of major tree species in high altitudes of Nepal Himalaya.
2. To collect tree cores of major species from three protected areas: Kanchenjungha (east), Rara (west) and Api-Nampa (far-west); and
3. To assess the impact of climate change on vegetation shifts and reconstruct the climatic history of the sites.

MATERIALS AND METHODOLOGY

Study area

Three study areas were selected for the present research: i) Kanchanjungha Conservation Area, ii) Rara National Park, and iii) Api-Nampa Conservation Area covering the eastern and western Nepal Himalaya (Fig. 1). KCA, established in 1997, covers 2,035 sq km in the Taplejung district in the north-east border of Nepal. The annual rainfall of the area is 1775m. It ranges from subtropical vegetation in the lower mid-hills to alpine grasslands in the high hills and mountains. RNP, established in 1976, lies in northwestern Nepal covering parts of Mugu and Jumla districts. The park is Nepal's smallest protected area, with 106 sq km. Its main feature is Rara Lake at an altitude of 2990 m. The elevation of the park ranges from 2800 m to 4039 m (Chuchemara peak). The climate of the area is temperate to subalpine. ACA, established in 2010 is located in Darchula district in the far-western border of Nepal. It occupies 1903 sq km of area and the altitudes range from 539 m to 7132 m. The climate here is generally characterized by high rainfall and humidity.

Field visit and data collection

The field study was carried out in April (Kanchenjungha), May (Api-Napma), and June (Rara) 2014. In Kanchenjugha, the studied tree-line sites were at Ghunsa, in Api-Nampa at Chheti and Ranghadi, and in Rara at Chuchemara. These sites were situated at an elevation ranging from 3700 m to 4200m asl. Vertical transect plots (10-20 m X 100 m) were marked out in the tree line ecotones. Individuals were enumerated into three classes: tree (height >2 m), saplings (height: 0.5-2 m), and seedlings (height <0.5 m) following the classification given by Kullman (2007) and Wang et al (2006). Census was carried out inside the plots for *A. spectabilis* and *B. utilis*. For every *A. spectabilis* and *B. utilis* individuals within the plot, location, size (diameter at breast height, height), and growth form were recorded. The age of seedling and sapling of conifer was determined by counting the branch whorl of all the individuals.

Three MSc students of Tribhuvan University were included in the study: Bimal Sharma, Sanjaya Bhandari and Rup Raj Timilsina. A five-day training workshop (Feb 3-7, 2014) was organized to enhance climate change research capability of young researchers. Altogether 15 researchers including research team members were benefited from the training.

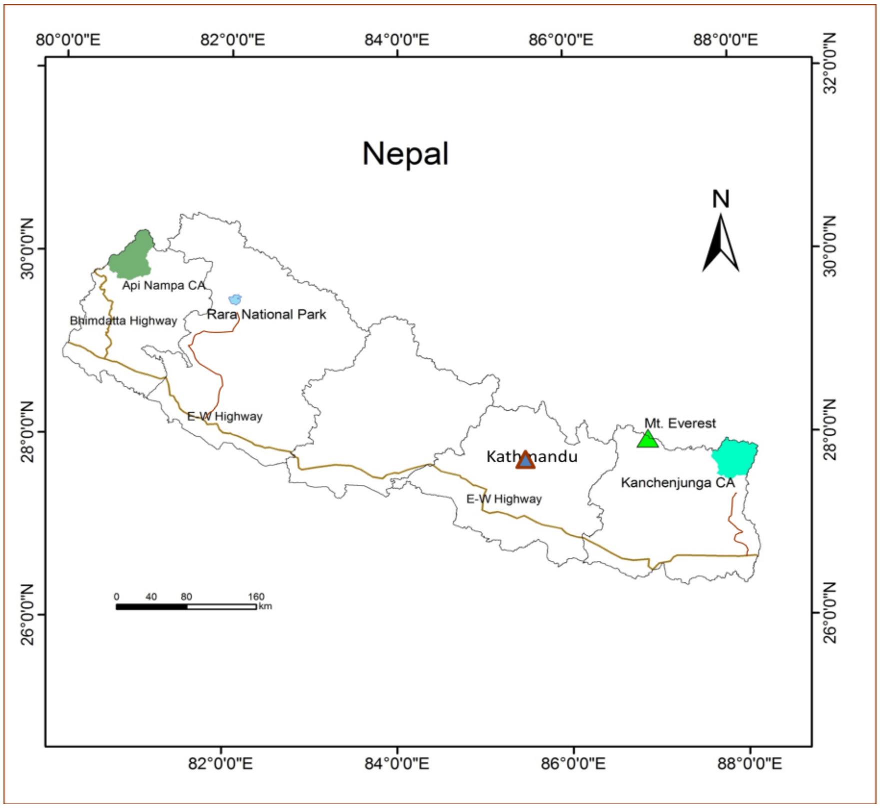

Fig. 1. Study Sites, Kanchenjungha Conservation Area (Taplejung), Rara National Park (Mugu) and Api-Nampa Conservation Area (Darchula). The road connection via east-west highway is seen, but not in scale.

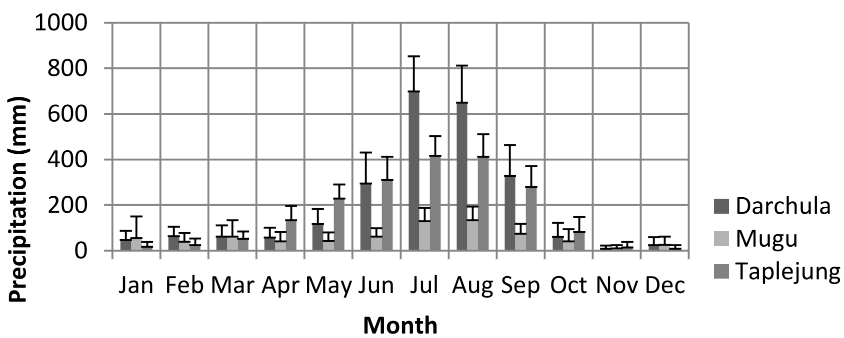

Fig. 2. Monthly Average Precipitation (with Standard Deviation) in nearby stations of the Study Area.

Tree-cores sampling and procession

Tree-cores were collected from *A. spectabilis* and *B. utilis*, from the base and some tree at breast height (1.3 m). Cores from the larger *A. spectabilis, B. utilis, Picea smithiana* and *Tsuga dumosa* trees not restricting in the plots were also collected for dendrochronological analysis and climate reconstruction. Collected tree increment cores and cut stump samples were proceeded for laboratory analysis at Dendro-Lab of Nepal Academy of Science and Technology (NAST). The collected cores were air-dried and glued into grooved sticks with the transverse surface facing up. The specimen details such as site name, date, etc. were written on the mount. The surface of these cores was cut and polished with different grades of sandpaper ranging from 100 to 1000 grits so that rings get visible to study under the microscope.

Measurement and cross-dating of the tree-rings

The germination date was estimated by taking out a core from each live individual's main stem as close to the ground as possible. Core rings were counted under a stereo zoom microscope. The ages of seedling and sapling were estimated by counting its branch whorls and scars along the main stem. This age estimation was validated comparing it with the age obtained by counting the tree-rings in basal disks taken from a subsample of trees located outside but near to the plot. Inner- ring dates were corrected using age-height/age-diameter regression. After dating the tree-ring sequences to the exact calendar year of their formations, the width of each ring was measured to the nearest 0.01 mm precision with the LINTAB^{TM} measuring system attached to the PC and the TSAP package (Rinn 2003). The alignment plotting technique of cross-dating was used to date all properly mounted tree-ring samples. Collected tree cores were cross-dated by matching patterns of relatively wide and narrow rings to account for the possibility of ring-growth anomalies such as missing or false rings (Fritts 1976).

Error detection and Chronology development

After the measurement of the ring width of each dated sample, the dating of each sample was checked using a computer program, COFECHA, a computer-assisted quality control program (Holmes 1983). The corrected ring-width series were standardized using the computer program ARSTAN (Cook 1985). Various statistics such as Mean sensitivity, Standard Deviation, Autocorrelation, Mean series correlation, Signal-to-noise ratio, Expressed population signal, and Percentage of variance explained by the first eigenvector of the chronologies were used for analysis.

Climatic influence on tree-line dynamics

The tree-line expansion was studied with the age of individuals' in the tree-line ecotone following Camarero and Gutiérrez (2004). To calculate the rate of tree-line shift, the maximum elevation of live individuals with stems at least 2m high was determined (maximum tree-line elevation). The tree-line shift rate (m/yr) was calculated by dividing the change in tree-line elevation by the time elapsed. The tree-line advanced (rate >0) or remained stable (rate = 0) during all the considered periods at the studied sites was determined. To describe the climate-recruitment relationships monthly climatic data (maximum and minimum temperatures, total precipitation) from the nearby meteorological station were used. (Detailed study on tree-line dynamics is in progress).

Climate relationship and Reconstruction

The study of climate relationships and past climate reconstruction is in progress. The DENDROCLIM2002 computer program was used for response analysis to examine the relationship between tree ring growth and climate (Biondi & Waikul, 2004). The significant correlations obtained between ring-width chronology and climatic variables will be taken as the basis to develop the transfer function to reconstruct the past regional climate.

RESULTS AND DISCUSSION

Climate of the study area

Monsoon dominates the climate of the study area with 72-88% precipitation coming during the monsoon season of June to September. Fig. 2 presents the monthly precipitation in the nearby stations of the study area. July received the highest precipitation while November-December received the lowest precipitation compared with other months.

Position of species line/limit and treeline

Table 1 presents the position of the tree-line and species limits. *A. spectabilis* limit was found at 3870m in Chuchemara of Rara and 3763 m in Deuthani (Chheti) and 3768 m in Makarchuli

(Ranghadi) in Api-Napma. *Betula* tree-line and species-line was found at 3953 m in Chuchemara of Rara and 3845 m in Deuthani area and 3802 m in Makarchuli of Api-Nampa. The variation in the position of the species-line and tree-line might be due to differences in latitudinal position and associated topo-climatic influences. This position will be the geo-referenced baseline position to study future tree-line shifting analysis with climate change. In a study, Gaire et al (2014) recorded the species limit of *A. spectabilis* was at 3984m (GPS e-Trex), and *B. utilis* species limit at the same aspect in 4003m in Manaslu Conservation Area in central Nepal.

Structural parameters of *Betula utilis*

In Kanchenjungha, the average DBH and height of *B. utilis* was 7.1 cm and 3.1 m respectively, and the average age was 40.5 years. As very few *A. spectabilis* were present in this site, growth parameters were not calculated. Fig. 3 presents the size class distribution of *B. utilis* in studied transects. The DBH and diameter at the base class distribution of *B. utilis* was slightly an inverse J shaped in distribution indicating continuous regeneration of the species in the forest. The height class was dominated by 3-4 m height class indicating that the forest was in the growing stage. In elevation distribution, younger age trees were found with increasing elevation indicating an upward shifting of the species. From the preliminary analysis, the upward shifting of this species was found 2.4 m/yr during the past over 130 years.

In Rara Site 2, the average DBH and height of *A. spectabilis* was 37.6 cm and 8.9 m respectively (Table 2). All the average growth parameters of *B. utilis* were low in Site 1 compared to that at Site 2, which indicates that in Site 1 has regenerating trees. *A. spectabilis* was absent in Site-1; In Site-2, its DBH class distribution was multimodal indicating sporadic regeneration. However, the DBH distribution of *B. utilis* in both sites was almost an inverse J shaped distribution indicating continuous regeneration. Fig. 4 presents the size class distribution of *Abies* and *Betula* in studied transects. Stand observation in the field indicated that there were more matured *Betula* trees than that of *Abies*. Most of the *Betula* trees were 30-70 years with few old individuals.

Table 1. Position of tree-line (m asl) in Kanchenjungha, Rara and Api-Nampa

	Kanchenjungha Taplejung	Rara Mugu		Api-Nampa Darchula	
	Ghunsa	T1	T2	Chheti (Deuthani)	Ranghadi (Makarchuli)
Abies sp limit	4136	Below 3850	3870	3763	3768
Abies treeline	4118	Below 3851	3870	3731	3738
Betula sp limit	4132	3953	3905	3845	3802
Betula treeline	4132	3953	3893	3845	3802

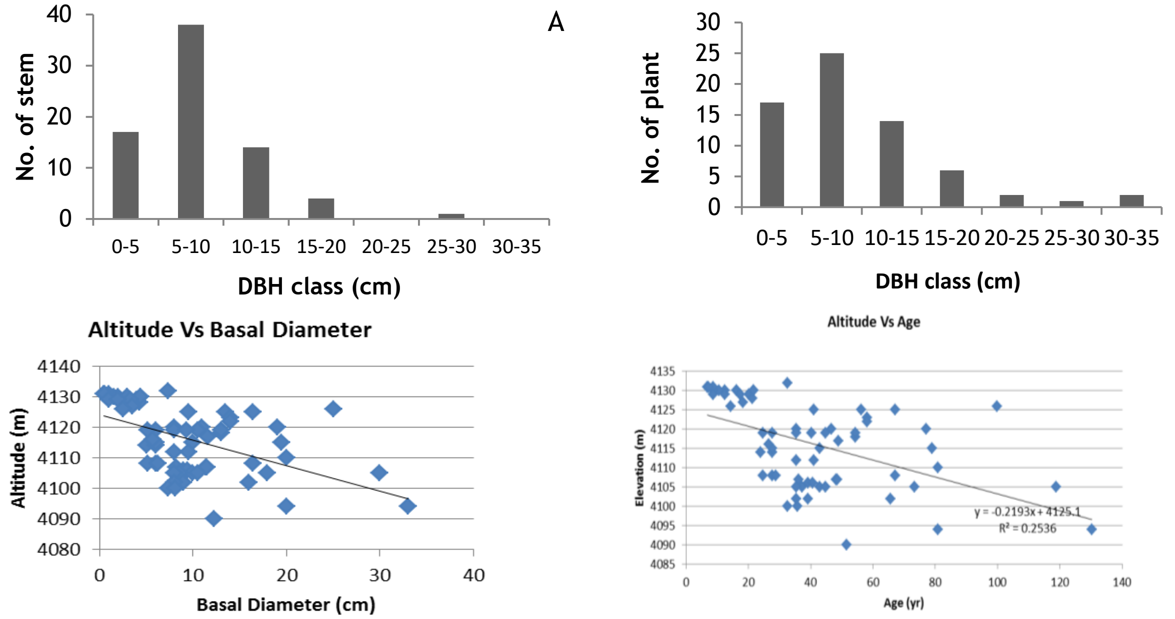

Fig. 3. A&B: Diameter Class Distribution of *Betula utilis* in Kanchenjungha Conservation Area, Taplejung, Nepal. C: Altitude vs Basal Diameter and E: Correlation between Altitude and Age.

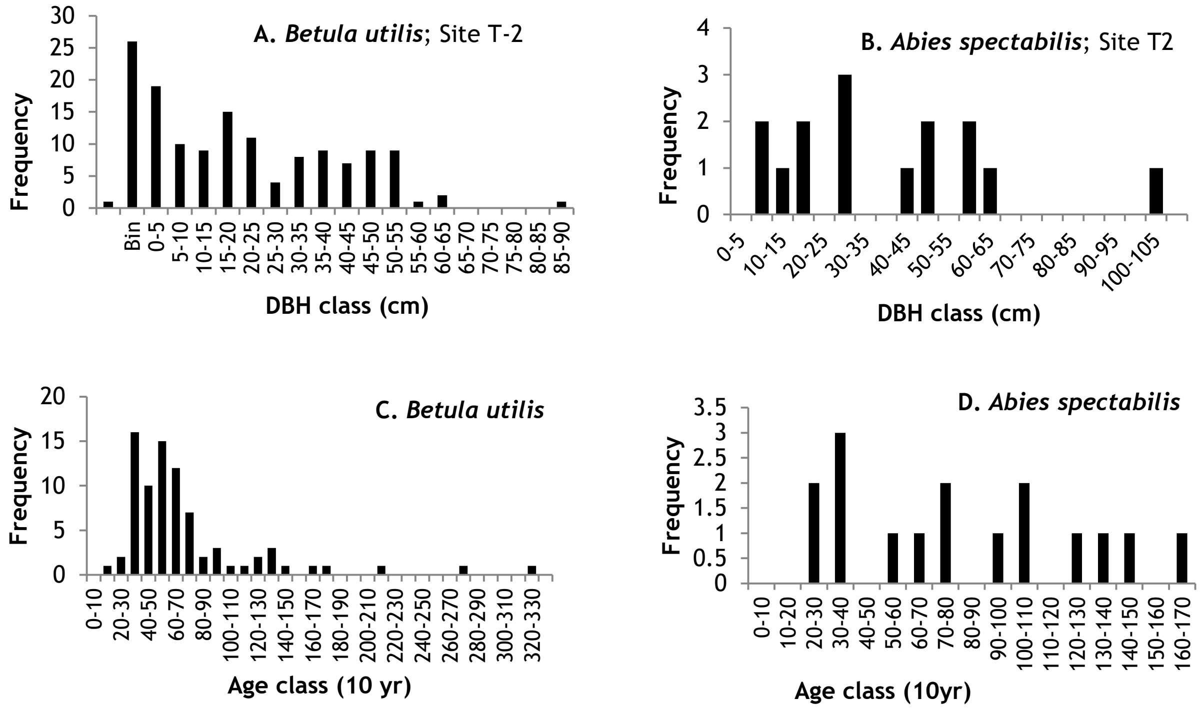

Fig. 4. A&B Diameter class distribution and C&D Age Class of *Betula utilis* and *Abies spectabilis* in Rara National Park, Mugu, Nepal; C&D Age class distribution of the same species

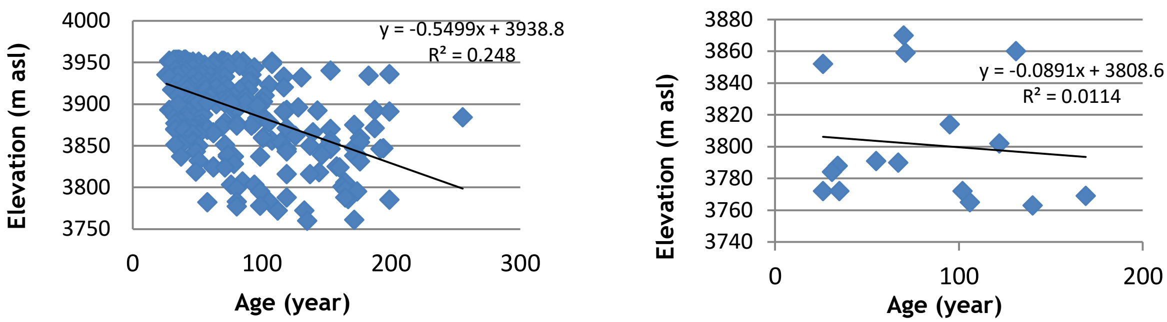

Fig. 5. Age of *Betula utilis* and *Abies spectabilis* along an elevation in Chuchemara, Rara National Park, Mugu, Nepal

Table 2 A. Descriptive statistics of growth and size parameters of *Abies spectabilis*

Statistics	Kanchenjungha				Rara				Api-Nampa			
	DBH (cm)	Basal diam. (cm)	Ht (m)	Age (yr)	DBH (cm)	Basal diam. (cm)	Ht (m)	Age (yr)	DBH (cm)	Basal diam. (cm)	Ht (m)	Age (yr)
Mean	3.4	6.8	1.2	14.3	37.6	44.3	8.9	80.0	8.9	9.0	2.3	25.2
Standard Error	0.3	1.2	0.4	2.8	6.7	7.0	1.3	11.3	1.6	1.9	0.6	3.2
Standard Dev.	0.6	3.0	1.0	4.9	26.1	27.0	5.2	45.2	5.4	7.7	2.6	13.7
Minimum	2.5	1.1	0.2	11.0	7.0	9.0	1.5	26.0	3.0	2.0	0.3	7.0
Maximum	4.0	9.0	2.5	20.0	104.0	108.0	17.0	169.0	21.0	32.0	8.6	54.0
Conf. Level 95%	1.0	3.2	1.2	12.3	14.4	15.0	2.8	24.1	3.44	3.97	1.28	6.8

Table 2 B. Descriptive statistics of growth and size parameters of *Betula utilis*

Statistics	Kanchenjungha				Rara				Api-Nampa			
	DBH (cm)	Basal diam. (cm)	Ht (m)	Age (yr)	DBH (cm)	Basal diam. (cm)	Ht (m)	Age (yr)	DBH (cm)	Basal diam. (cm)	Ht (m)	Age* (yr)
Mean	7.8	9.4	3.1	40.5	29.6	35.3	6.9	107.6	15.2	19.4	7.6	
Standard Error	0.5	0.8	0.2	3.1	1.7	2.0	0.3	18.5	1.6	2.2	0.6	
Standard Dev.	4.7	6.7	1.5	25.5	20.0	23.0	3.0	69.3	11.7	15.1	4.1	
Minimum	0.1	0.5	0.4	7.0	4.0	5.0	1.8	26.0	1.0	3.0	0.6	
Maximum	28.3	33.0	7.3	130.0	96.0	105.0	12.5	275.0	46.0	80	14.0	
Conf. Level 95%	1.1	1.6	0.4	6.2	3.3	3.9	0.6	40.0	3.26	4.4	1.18	

* In progress

Table 3. Summary of the core collection from the study sites.

SN	Site	Species	No of samples	Max age (yrs)
1	Kanchenjungha Taplejung	*Betula utilis*	80	224
2	Rara Mugu	*Abies spectabilis*	106	310
		Betula utilis	90	311
		Picea smithiana	102	361
		Cedrus deodara	60	312
3	Api-Nampa Darchula	*Abies spectabilis*	70	NA
		Betula utilis	120	NA
		Tsuga dumosa	89	357

In the Deuthani site of Api-Nampa, the average DBH and height of *A. spectabilis* was 8.9 cm and 2.3 m respectively (Table 2). This indicates the dominance of young individuals and recent regeneration. The DBH class distribution of both the species, *B. utilis* and *A. spectabilis* showed slightly an inverse J-shaped in the Deuthani area indicating the presence of the young individuals and recent regeneration. The decreasing trend of all the growth parameters of the species with increasing elevation indicates that the tree-line of the area is changing.

Gaire et al (2011) observed an inverse J shaped to bell-shaped distribution of *A. spectabilis* and slightly bimodal distribution of DBH of *B. utilis* in tree-line ecotone of Langtang National Park, and recorded the diameter up to 115.5 cm for the species. From a study of high-altitude tree-line ecotone of the Khumbu region of eastern Nepal, Bhuju et al (2010) observed bell shaped diameter class distribution of *A. spectabilis* and inverse J-shaped distribution of *B. utilis* at tree-line and vice-versa pattern of diameter distribution of these two species at timber-line. The same study recorded 99 cm DBH of *A. spectabilis* and 63 cm DBH of *B. utilis*. The DBH distribution of *A. spectabilis* was an inverse J shaped to bimodal distribution while the DBH distribution of *B. utilis* was unimodal bell-shaped in a tree-line ecotone of Manaslu (Gaire et al 2014).

Treeline shifting

Distribution of seedling, saplings, and tree individuals of *A. spectabilis* and *B. utilis* in Rara presents that there is a decreasing trend in age with increasing elevation. This indicates shifting of the species in the past (Fig. 5). A similar pattern of tree-line dynamics is seen in Kanchenjungha (Fig. 3), in Api-Nampa it is more prominent. Recruitment is among the most critical determinants of the rate of forest shift to climatic change (Camarero & Gutierrez 2007). Other studies have also presented differential recruitment and shifting rate for *Abies* and *Betula* in different tree-line sites of Nepal (e.g. Bhuju et al 2010, Suwal 2010, Gaire et al 2011). Gaire et al (2014) revealed more mature *B. utilis* (max. age 198 yrs) compared to *A. spectabilis* (max. age 160 yrs) in tree-line ecotone of Manaslu. *(B. Sharma is preparing MSc thesis on species shift in Kanchenjungha)*.

Site chronology

A total of 717 tree-cores of five species were collected from their dominant stands below the tree-lines in the study sites of three protected areas, Kanchenjungha, Rara, and Api-Nampa (Table 3). The species included *A. spectabilis* (total sample 176; max. age 310 in Rara), *B. utilis* (total sample 290; max. age 311 in Rara), *Cedrus deodara* (total sample 60; max. age 312 in Rara), *Picea smithiana* (total sample 102, max. age 361 in Rara), and *Tsuga dumosa* (total sample 89; max. age 357 in Api-Nampa). Figs. 6 and 7 present site chronology statistics of *T. dumosa* and *P. smithiana*, which were collected from Api-Nampa and Rara respectively. Site chronology of *T. dumosa* presented an extension from AD 2013 to 1656, which is 357 years. The years 1677, 1741 and 1965 had narrower rings but the years 1685, 1738, and 2006 showed wider rings. The average annual ring growth of *T. dumosa* was found to be 1.68 mm and 1.43 mm in Chheti and Ranghadi area cores from Api-Nampa. The mean annual radial growth of *T. dumosa* was found to be 1.61 mm per respectively. A chronology of 357 years of *T. dumosa* was developed by using the collected year. Based on the tree-core samples of *P. smithiana*, a site chronology of 315 years extending from 1699 to 2013 AD was prepared. Mean radial growth was found 1.44 mm per yr. This chronology shows several periods of high and low growth in it. The growth pattern shown in this chronology is similar to the growth pattern obtained by Thapa (2013) in the Khaptad, western Nepal. (*S. Bhandari and R.R. Timilsina are defending their MSc thesis on T. dumosa and P. smithiana respectively.)*

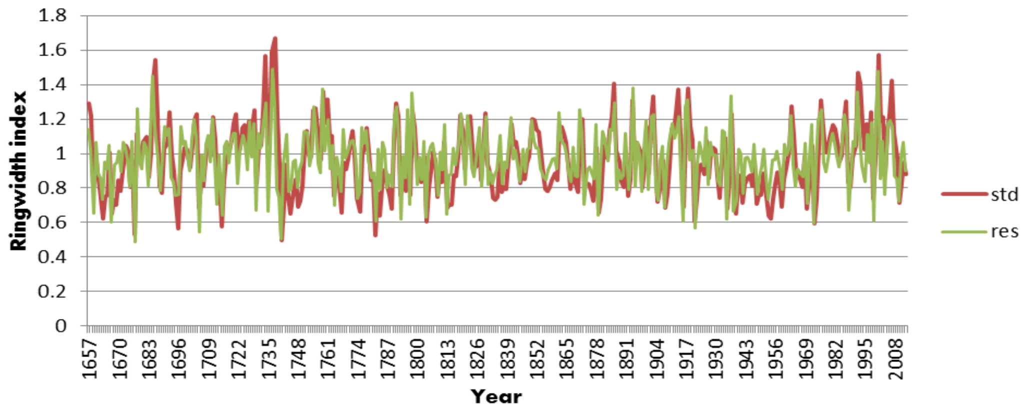

Fig. 6. Site Chronologies of *Tsuga dumosa* from Api-Nampa Conservation Area, Darchula, Nepal

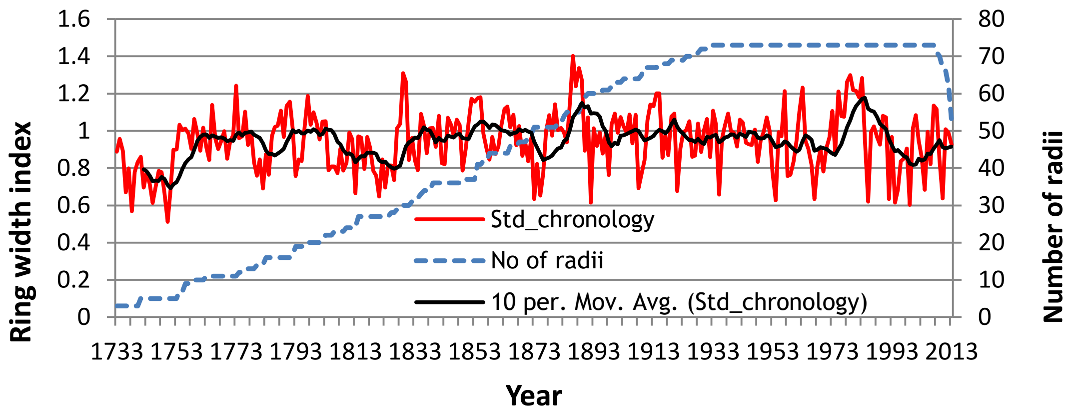

Fig. 7. Site Chronology of *Picea smithiana* from Rara. Black Solid Line shows the 10 Year Low Pass Filter.

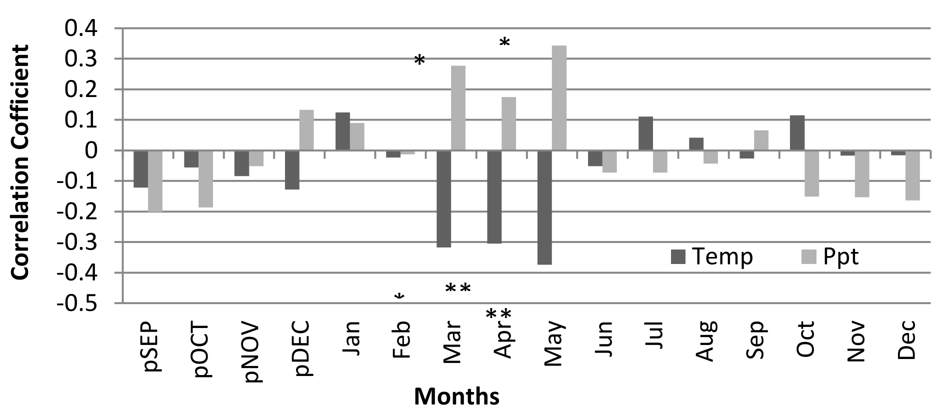

Fig. 8. Pearson's Correlation Coefficient Analysis of Ring Width Growth of *Tsuga dumosa* and Average Monthly Temperature in Mukteshwar India and Precipitation in Darchula, Nepal. Capital Letters Indicate Months of Previous Year.* Denotes Correlation Significant at 95% and ** Denotes Correlation Significant at 99%.

Fig. 8 presents a correlation analysis of tree growth climate relationship of *T. dumosa*. Temperature and precipitation data of Khalanga (Darchula) as well as temperature data of

Mukteshwar (India) were used. Monthly temperature and precipitation variables from month September of the previous growth year to the October of current growth year were used as predictors and tree ring data as the predictants. The ring growth response showed a significant negative relationship with the temperature of the pre-monsoon months March, April and May. However, a positive relationship was found with the precipitation of the same three months of pre-monsoon season. But the growth of *T. dumosa* showed a slightly negative relationship with both temperature and precipitation of the previous year September, October, November. Growth responds positively with the mean temperature and precipitation of the current year in January. This indicates that moisture availability in these months limits the growth of *T. dumosa*. Strong solar radiation at high elevation, temperature could increase drought stress by enhancing evaporation resulting negative correlation between the growth and the mean temperature of pre-monsoon season (Sano et al 2005, Dawadi et al 2013).

Bhattacharya et al. (1992) and Cook et al (2003) had indicated that *T. dumosa* can be used in the dendrochronological study because of good cross dating characteristics. In this present study 357 years, long tree ring width chronology extending back to AD 1657 was developed by using core samples of *T. dumosa* which were collected from Api-Nampa area. Cook et al (2003) had developed 1141 years long tree ring width chronology using *T. dumosa*, which is the oldest tree reported in Nepal. Thapa et al (2014) developed 362 years long tree ring width chronology of *Abies pindrow*, extending back to AD 1650 from Khaptad. Similarly, Sano et al. (2005) had developed 283 years long tree ring width chronology of *A. spectabilis* from Jumla, mid-western Nepal. Likewise, Gaire et al (2014) developed 229 years long tree ring width chronology of *A. spectabilis* from Manaslu. In the same manner, Dawadi et al (2013) developed tree ring width chronology of 458 years of *B. utilis* from Langtang.

The comparable response of tree ring width growth was found in the study of Thapa et al (2013) in *A. pindrow* of western Nepal Himalaya (Khaptad). Sano et al (2010) also reported that the growth of *A. spectabilis* was limited by the pre-monsoon months in Humla, north-west Nepal. Similarly the growth of *B. utilis* in Langtang was positively correlated with the temperature of March, April and May but negatively correlated with precipitation of the same three months (Dawadi et al 2013). But the growth of *A. spectabilis* in Langtang showed positive correlation only with total monthly precipitation month March and a negative correlation with the minimum temperature of month May. On the other hand, Gaire et al (2014) reported a weak correlation of *A. spectabilis* with precipitation, having a significance negative correlation only with February precipitation in Manasalu Conservation Area, central Nepal Himalaya indicating snow accumulation delays the growth initiation, shortening the growth period and ultimately resulting narrow ring.

CONCLUSION

The study observed that the position of tree-line decreased from eastern Nepal to western Nepal. Species composition in the tree-line is almost similar in all study areas depending on the aspect of the slope. The size class distribution shows the site-specific and species-specific regeneration pattern. The elevation-wise size class distribution shows the dynamic nature of the tree-line in all study areas. Preliminary results of *A. spectabilis* showed that this species was shifting upward at 2.4 m/yr. The collected tree cores samples shows the dendroclimatic potential and these cores can be used for dendroclimatic reconstruction. From the *Tsuga* samples, past climate for over 300 years can be reconstructed. The response of multiple species to climate will have importance for forest management as well as climate reconstruction with high precision. It is feared that the species shift towards alpine meadow will have to bring a direct impact on the livelihood of the high mountain dwellers; thus the present study will also have policy implications in exploring the livelihood options of these people.

REFERENCES

Bhattacharyya, A., V.C. Lamarche, J.R. and M.K. Hughes 1992. Tree ring chronologies from Nepal. *Tree Ring Bulletin* 52: 59-66.

Bhattacharyya, A., S. K. Shah and V. Chaudhary. 2006. Would tree ring data of *Betula utilis* be potential for the analysis of Himalayan glacial fluctuation? *Current Science* 91(6): 754-761.

Bhuju, D.R., M. Carrer, N.P. Gaire, L. Soraruf, R. Riondato, F. Salerno and S.R. Maharjan. 2010. *Dendroecological study of high altitude forest at Sagarmatha National Park, Nepal*. In: Contemporary research in Sagarmatha (Mt. Everest) region, Nepal (eds. Jha, P.K. and Khanal, I.P.). Nepal Academy of Science and Technology, Kathmandu. 2010, pp.119-130.

Biondi, F. & K. Waikul. 2004. DENDROCLIM2002: AC++ program for statistical calibration of climate signals in tree-ring chronologies. *Computers & Geosciences* 30: 303–311.

Bradley, R.S. and P.D. Jones. 1993. 'Little Ice Age' summer temperature variations: their nature and relevance to recent global warming trends. *The Holocene* 3: 367–376.

Camarero, J.J. and E. Gutiérrez. 2004. Pace and pattern of recent treeline dynamics: response of ecotones to climatic variability in the Spanish Pyrenees. *Climatic Change* 63: 181–200.

Cook, E.R., P.J. Krusic and P.D. Jones. 2003. Dendroclimatic Signals in Long Tree- Ring Chronologies from the Himalayas of Nepal. *International Journal of Climatology* 23: 707–732. (www.interscience.wiley.com). DOI: 10.1002/joc.911

Cook, E.R. 1985. *A time series analysis approach to tree-ring standardization*. PhD dissertation, University of Arizona, Tucson, AZ.

Dawadi, B., E. Liang, L. Tian, L.P. Devkota and T. Yao. 2013. Pre-monsoon precipitation signal in tree rings of timberline *Betula utilis* in the Central Himalayas. *Quaternary International* **283:** 72–77.

Dhakal, Y.R. 2009. *Forest ecology and tree ring pattern at the tree-line of Langtang National Park, Nepal Himalaya*. MSc. dissertation submitted to Central Department of Environmental Science, Tribhuvan University, Kathmandu.

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

Gaire, N.P., Y.R. Dhakal, H.C. Lekhak, D.R. Bhuju and S.K. Shah. 2011. Dynamics of *Abies spectabilis* In relation to climate change at the tree-line ecorone in Langtang National Park Nepal. *Journal of Science and Technology* 12: 220-229.

Gaire, N.P., D.R. Bhuju, M. Koirala and H.P. Borgaonkar. 2014. Tree-line dynamics with climate change at central Nepal Himalaya. *Climate of the Past* 10: 1277–1290, www.clim-past.net/10/1277/2014/doi: 10.5194/cp-10-1277-2014.

Holmes, R. L. 1983. Computer assisted quality control in tree ring dating and measuring. *Tree-Ring Bull*. 43: 69–78.

IPCC, 2007. *Climate change 2007: the physical sciences Basis*. Summary for Policy Makers, IPCC: 21. Geneva: IPCC.

Kharal, D.K., H. Meilby, S. Rayamajhi, D.R. Bhuju and U.K. Thapa. 2014. Tree ring variability and climate response of *Abies spectabilis* along an elevation gradient in Mustang, Nepal. *Banko Jankari* 24 (1): 3-13

Kullman, L. 2002. Rapid recent range-margin rise of tree and shrub species in the Swedish Scandes. *Journal of Ecology* 90: 68-77.

Kullman, L. 2007. Treeline population monitoring of *Pinus sylvestris in* the Swedish Scandes, 1973–2005: implications for treeline theory and climate change ecology. *Journal of Ecology* 95: 41–52.

Rinn, F., 2003. TSAP-Win: time series analysis and presentation for dendrochronology and related applications. Version 0.55 User reference. Heidelberg, Germany. http://www.rimatech.comSalzer

Sano, M., F. Furuta, O. Kobayashi and T. Sweda. 2005. Temperature variations since the mid-18th century for western Nepal, as reconstructed from tree-ring width and density of *Abies spectabilis*. *Dendrochronologia* 23: 83–92.

Suwal, M.K. 2010. *Tree species line advance of Abies spectabilis in Manaslu Conservation Area, Nepal Himalaya*. M.Sc. Thesis. Central Department of Botany, Tribhuvan University, Kathmandu.

Thapa U.K., S.K. Shah, N.P. Gaire, D.R. Bhuju, A. Bhattacharyya, G.S. Thagunna. 2013. Influence of climate on the radial growth of *Abies pindrow* in western Nepal Himalaya, *Banko Jankari*, 23(2): 14-19.

Udas, E. 2009. Influence of climate variability on the growth performance of *Abies spectabilis* at tree

line of West-central Nepal. Master Thesis, University of Greifswald, Germany.
Wang, T., Q-B. Zhang and K. Ma. 2006. Treeline dynamics in relation to climatic variability in the central Tianshan Mountains, northwestern China. *Global Ecology and Biogeography* 15: 406–415.
Yadav, R.R., J. Singh, B. Dubey and R. Chaturvedi. 2004. Varying strength of relationship between temperature and growth of high-level fir at marginal ecosystems in western Himalaya, India. *Current Science* 86(8): 1152-1156.

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