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Contemporary and Historic Population Structure of *Abies spectabilis* at Treeline in Barun Valley, Eastern Nepal Himalaya

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Abstract: Treeline ecotone dynamics of *Abies spectabilis* (D. Don) Mirb. in the Barun valley, Makalu Barun National Park, eastern Nepal Himalaya were studied by establishing seven plots (20 m × variable length) from the forestline to the tree species limit: three plots on the south- and north-facing slopes each (S1-S3, N1-N3), and one plot on the east-facing slope (E) in the relatively undisturbed forests. A dendroecological method was used to study treeline advance rate and recruitment pattern. In all the plots, most trees established in the early 20th century, and establishment in the second half of the 20th century was confined to the forestline area. Treeline position has not advanced substantially in the Barun valley, with only 22 m average elevational shift in the last 130 years, and with average current shifting rate of 14 cm/yr. Moreover, no significant relationship was found between tree age and elevation on the south-, north-, and east-facing slopes. The number of seedlings and saplings in near the treeline area was negligible compared to that near the forestline area. Therefore, *A. spectabilis* treeline response to the temperature change was slow, despite the increasing temperature trend in the region. Beside the temperature change, factors such as high inter-annual variability in temperature, dense shrub cover, and local topography also play an important role in treeline advance and controlling recruitment pattern above the treeline.

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Keywords: Climate change; Treeline ecotone; Treeline advance; Recruitment pattern

Introduction

The treeline ecotone is the altitudinal zone between the tree species limit and forestline (Hofgaard et al. 2009), where the forestline is the upper delimitation of the closed forest and the tree species limit the uppermost location of seedling or sapling (Motta and Nola 2001; Hofgaard et al. 2009). One of the main factors that controls treeline ecotones worldwide is climate, and in particular, temperature (Körner 2012). In fact, increases in temperatures can cause changes in treeline ecotone structure and pattern (Jump et al. 2007; Hofgaard et al. 2009; Liang et al. 2011; Kharuk et al. 2013). However, there is variability of treeline response to climate: some treeline are advancing (Devi et al. 2008; Vittoz et al. 2008), some are stable (Klasner and Fagre 2002; Wang et al. 2006), and some are receding (Kullman 2007; Zhang et al. 2010). In an extensive review of 166 treeline related studies from around the world Harsch et al. (2009) found that the treeline ecotones are advancing at 52% of these sites in response to global climate warming, stable at 46% of the sites, and receding at 2% of the sites. However, most of these sites were from North America and Europe, and the Himalayan region has been underrepresented both in this study, and more generally. The Himalayan alpine ecosystems are more vulnerable to climate warming but poorly investigated so far. Several researchers (e.g. Schickhoff (2005), Holtmeier (2009), Shi and Wu (2013)) have noticed the variety of treeline structure and growth forms in the Himalaya and indicated that little is known about the spatial distribution of the treeline ecotone. Focusing on an understudied area like the Himalaya will help to understand the broad ecological questions associated with treeline formation worldwide.

The Himalaya region is very sensitive to global climate change (Xu et al. 2009), and the treeline ecotone could shift upward in response to warming temperatures (Liang et al. 2011). Few studies, however examine the response of the Himalayan treelines despite the increasing temperature trend. Most of these studies such as Dubey et al. (2003), Baker and Moseley (2007), and Panigrahy et al. (2010) were based on remote sensing and repeat photography techniques. Local field-based observation of the recruitment pattern at the treeline ecotone is still lacking in this region (Schickhoff et al. 2014). Therefore, there is need of more field-based data to understand treeline dynamics. Such a field-based study of spatial and temporal patterns of trees at a local scale increases our understanding of the treeline ecotone response to climate warming (Wang et al. 2012). Studies conducted at the plot scale study will help to understand the change in age structure, recruitment pattern, and biological response of individual trees. Moreover, the ecology of the Himalayan treeline ecotones varies with slope aspect (Schickhoff et al. 2014). The majority of the diffuse and less disturbed treelines are limited to north facing slopes. Therefore, a study focusing on multiple aspects will be able to catch variation in treeline with aspect.

A recent study indicates that air temperature is increasing in the eastern Himalaya (eastern Nepal and eastern Tibet) with a relatively greater warming trend than other parts of the Himalaya (>0.02°C/yr) and this trend is more distinct at the higher elevations and in the winter season (Shrestha and Devkota 2010). In the Nepal Himalaya, only a few extensive scientific studies have been carried out to understand the impact of temperature increase on treeline ecotone dynamics and recruitment patterns. Recent studies in the treeline ecotone of Nepal hinted both at treeline advance (Gaire et al. 2014) and at stationary treelines (Shrestha et al. 2014), however, studies from a wider area are needed before coming to any solid conclusions. The treeline ecotone of the Nepal Himalaya is characterized by contrasting climatic, orographic, and anthropogenic conditions. The role of geomorphic processes and patterns, and human disturbance in shaping the spatial structure of the treeline ecotone should be separated from the climatic factors. In the absence of topographic influences and human activities, growth and recruitment in the treeline ecotones are mainly controlled by climate (Camarero and Gutierrez 1999). Therefore, the presence of saplings and seedlings above the treeline (Hofgaard et al. 2009), and their annual variation in abundance and distribution (Germino et al. 2002) are indicators of future changes in upper treeline stability. To characterize the history and potential for advance of the treelines in the eastern Himalaya in Nepal, we document the recruitment pattern of the treeline forming species *Abies spectabilis*. *A. spectabilis* is an important species in the subalpine conifer forest in the eastern Nepal Himalaya; however, very little is known about the recruitment pattern of this species in the region. The aims of this study of *A. spectabilis* in Barun valley, eastern Nepal Himalaya are to determine the present upper forest and treeline position, quantify the advance rate, and document the recruitment pattern at the treeline ecotone.

1 Materials and Methods

1.1 Study site

This study was carried out in the Barun valley (27º44'N-27º47'N, 87º08'E-87º10'E) of Makalu Barun National Park (MBNP), eastern Nepal Himalaya (Figure 1). Barun valley has no permanent human settlement. However, villagers from nearby buffer zone villages have been using this area for summer pasture since the 17th century (Byers 1996; Carpenter and Zomer 1996). Human activities are concentrated along river valley, and there is no cattle grazing and timber harvesting in the treeline ecotone, thus it can be considered as undisturbed. Barun valley contains glacially-fed

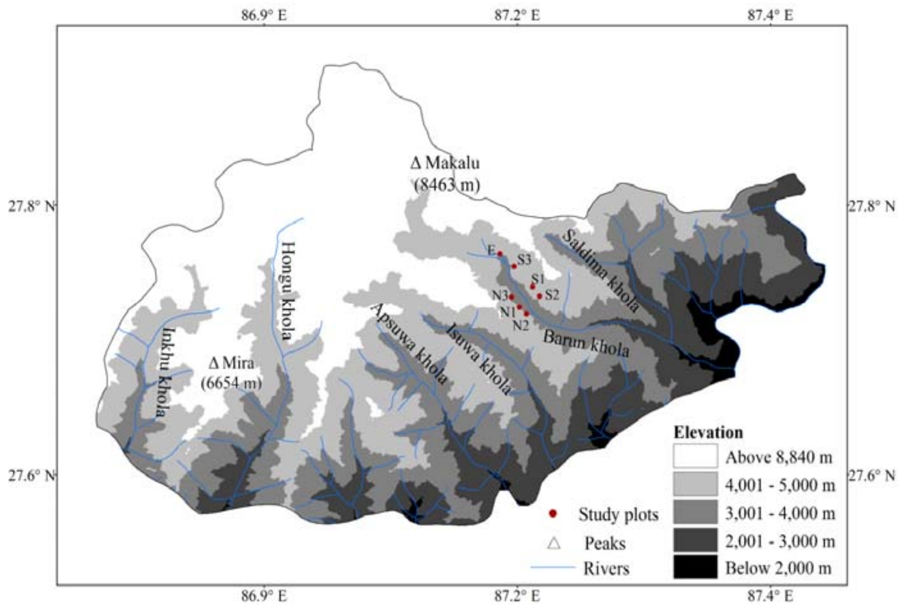

Figure 1 Location map of the study area: Makalu Barun National Park, and seven study plots – S1, S2, S3 (South exposed); N1, N2, N3 (North exposed) and E (East exposed) in Barun valley.

streams and shows evidence of the Pleistocene glaciation within the altitudinal belt occupied by subalpine forests today. Elevations above 2500 m are very fragile with high relief; over 73% have slopes in excess of 40° (Carpenter and Zomer 1996). *Abies spectabilis* (D. Don) Mirb. (Himalayan silver fir) is a treeline species and covers the south-, north- and east-facing slopes. Other associated species are *Betula utilis, Rhododendron hodgsonii, R. camplylocarpum*, *R. wightii*, *Acer campbelli*, and *Sorbus microphyllus*. The forest ground is covered with thick litter and mosses; and *Usnea* lichen grows on the tree trunks.

1.2 Climate

Barun valley lies within the subtropical Asian monsoon zone, characterized by a pronounced summer rainfall falling between June and September. Nearby meteorological stations (Figure 1) from study sites are at Num (about 24 km south from study site, 1497 m a.s.l) and Chialsa (about 60 km south-west from study site, 2770 m a.s.l). Num is a precipitation, and Chialsa is a temperature stations. Unfortunately, Chialsa station stopped recording the data in 1997. Analysis of precipitation data (1971-2009) indicates that 80% of the total precipitation occurred in June, July, August, and September (Figure 2). Temperature data (1967-1997) indicates that January (mean temperature 2.74°C) is the coldest month and July and August (mean temperature, 14.71°C) are the warmest months (Figure 2). To overcome this short time series climate station data, CRU 3.2TS climate data of the study area (27.25°-27.75°, 86.75°-87.25°, 1901-2009) (Mitchell and Jones 2005) was also used. Linear trend analysis of the CRU 3.2TS climate data shows the increasing trend in annual air temperature ($y = 0.0092x - 14.93$, $R^2 = 0.28$, $n = 110$, $p < 0.01$) and no clear increase or decrease trend in precipitation pattern ($y = -0.1073x + 336.33$, $R^2 = 0.04$, $n = 110$, $p < 0.01$) (Figure 2d). The seasonal warming trend in the region was also observed in CRU 3.2TS temperature data (Figure 2e).

1.3 Plot establishment

Field investigation was carried out in Oct-Nov, 2010 and Oct-Nov, 2011. Our objective was to investigate tree population structure at the treeline ecotone. Altogether, seven plots (20 m wide, variable length range from 50 m – 235 m) from the forestline to the tree species limit to cover the entire treeline ecotone were established (Table 1): three plots each at south- and north-facing slopes (S1-S3, N1-N3), and one plot at east-facing slope (E) (Figure 1). Selection of the plots was based on identifying climatic treelines, where possible treeline advance was not limited by local topography or geomorphological conditions (Elliott 2011). All the individuals of *A. spectabilis* within the plots were enumerated and classified into three-height classes: trees (> 2 m), saplings (0.5–2 m) and seedlings (< 0.5 m) (Wang et al. 2006; Kullman 2007). Forestline (cover of at least 30% in surface area of at least 500 m^2), treeline (position of the erect tree with a height of more than 2 m

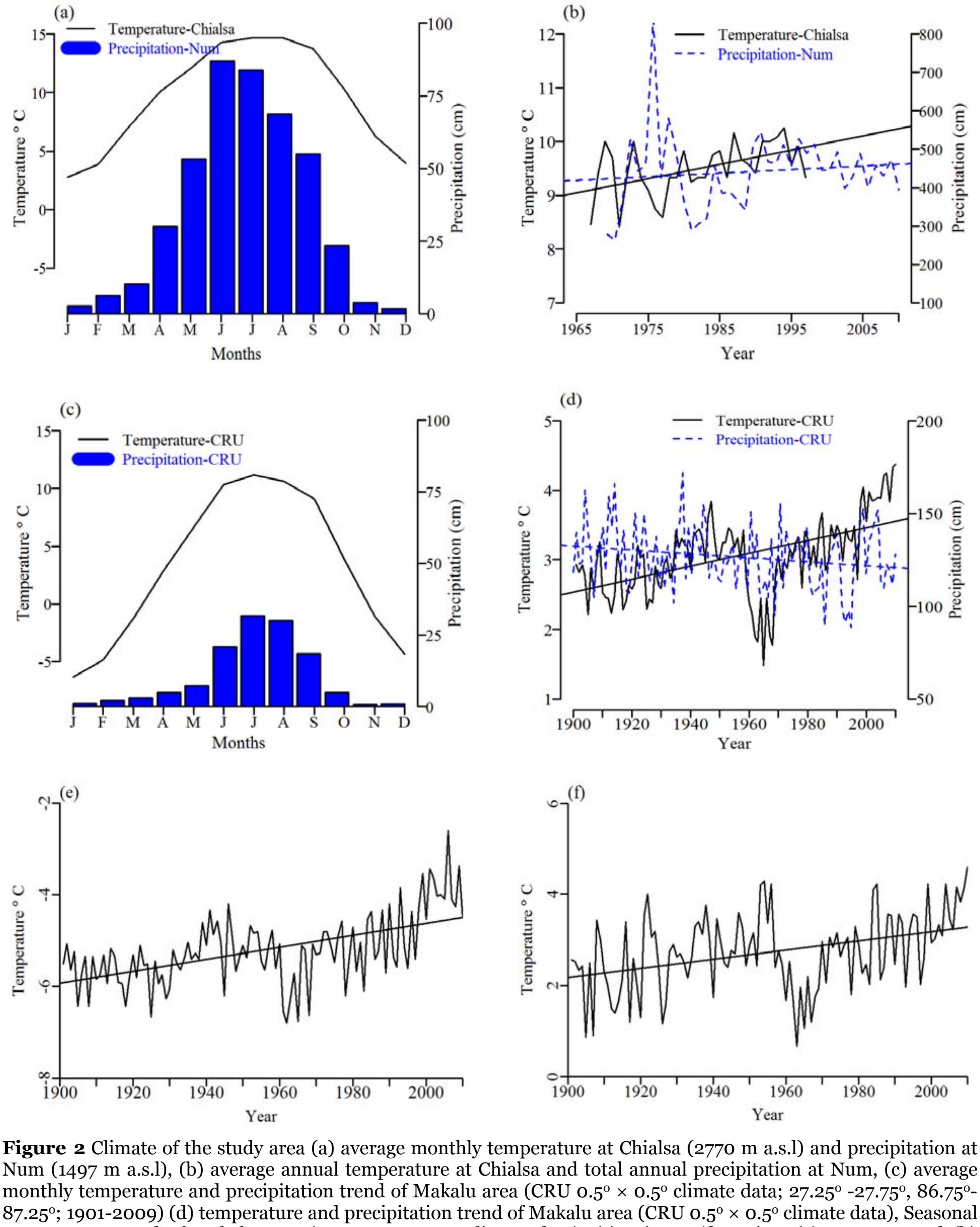

Figure 2 Climate of the study area (a) average monthly temperature at Chialsa (2770 m a.s.l) and precipitation at Num (1497 m a.s.l), (b) average annual temperature at Chialsa and total annual precipitation at Num, (c) average monthly temperature and precipitation trend of Makalu area (CRU 0.5° × 0.5° climate data; 27.25° -27.75°, 86.75°-87.25°; 1901-2009) (d) temperature and precipitation trend of Makalu area (CRU 0.5° × 0.5° climate data), Seasonal temperature trend of Makalu area (CRU 0.5° × 0.5° climate data): (e) Winter, (f) Spring, (g) Summer, and (h) Autumn. (-To be continued-)

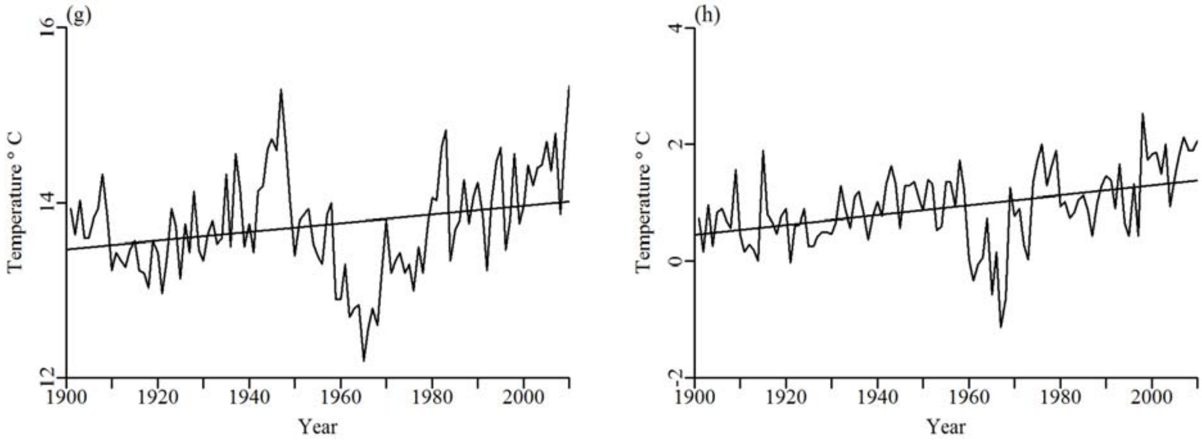

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Figure 2 Climate of the study area (a) average monthly temperature at Chialsa (2770 m a.s.l) and precipitation at Num (1497 m a.s.l), (b) average annual temperature at Chialsa and total annual precipitation at Num, (c) average monthly temperature and precipitation trend of Makalu area (CRU 0.5° × 0.5° climate data; 27.25° -27.75°, 86.75°-87.25°; 1901-2009) (d) temperature and precipitation trend of Makalu area (CRU 0.5° × 0.5° climate data), Seasonal temperature trend of Makalu area (CRU 0.5° × 0.5° climate data): (e) Winter, (f) Spring, (g) Summer, and (h) Autumn.

growing at the highest elevation) and tree species limit (uppermost location of tree seedling or sapling in the plot) were determined in the field (Motta and Nola 2001; Hofgaard et al. 2009; Liang et al. 2011; Shrestha et al. 2014). Within each plot coordinates and elevation of each individual of *A. spectabilis* was measured with the help of a GPS and an altimeter.

1.4 Dendroecological procedure

A total of 180 cores (S1-18, S2-33, S3-31, N1-23, N2-10, N3-12, and E-53) were collected from the base and eight cores (S1-2, S2-3, N2-1, N3-2) were collected above the base of trees with the help of an increment borer to determine the age of trees in seven established plots. Samples were prepared for further analyses by following standard dendrochronological procedures (Stokes and Smiley 1968). The age of cored samples was determined by ring counts using a stereomicroscope. Seven tree ring cores were later discarded due to decayed pith, and eight trees were cored above the base and afterward corrected by age-height correlation graph. The age of 1015 seedlings (S1-17, S2-56, S3-198, N1-66, N2-26, N3-64, E-588) and 131 saplings (S1-9, S2-11, S3-29, N1-8, N2-1, N3-10, E-63) present within the plots was determined by counting the number of branch node on the main stem (Camarero and Gutierrez 2004; Wang et al. 2006). This method can underestimate the true age (Camarero and

Table 1 Characteristics of the seven study plots (Unit of forestline, treeline, and species limit: m a.s.l.)

Plots	S1	S2	S3	N1	N2	N3	E
Latitude	27°45'40"N	27°45'28"N	27°46'28"N	27°45'05"N	27°44'59"N	27°45'25"N	27°47'25"N
Longitude	87°10'25"E	87°10'35"E	87°09'30"E	87°09'50"E	87°09'58"E	87°09'41"E	87°08'51"E
Aspect	South	South	South	North	North	North	East
Average slope	30-35°	30-35°	25-30°	30-35°	30-35°	30-35°	15-20°
Length (m)	60	140	95	80	160	50	235
Width (m)	20	20	20	20	20	20	20
Forestline	4031	3981	3934	3892	3856	3941	4034
Treeline	4058	4045	3969	3941	3960	3949	4092
Species limit	4060	4046	3969	3945	3964	3955	4095

Gutierrez 1999; Wang et al. 2006), so 76 cut samples (44 seedlings and 32 saplings) were also collected to cross check an error. Branch node method underestimates the age of seedlings and saplings by 2.4 ± 0.28 (SE) years compared to ring count method of cut stem at the root collar. The cut samples were also used for an age-height regression analysis to estimate the time to reach the breast height to remove the age error caused by coring height (Dang et al. 2010). Age-height correlation and regression analyses of cut samples were found to be statistically significant ($y = 0.129x + 5.89$, $R^2 = 0.65$, $n = 76$, $p < 0.01$) (Figure 3). Individuals with less than 3 years of age were excluded from the further analysis due to high mortality in this age class. *A. spectabilis* took 24 years to reach the breast height (1.37 m), and 32 years to attain the 2 m height. The establishment histogram was constructed using 10 year age classes (Szeicz and MacDonald 1995) by combining all the individuals of the study plots according to the slope. Kolmogorov-Smirnov test was carried out to see the difference in temporal recruitment pattern among south-, north- and east-facing slopes (Liang et al. 2011). All the analyses were carried out by using the R 3.1 statistical software (R Development Core Team 2014).

1.5 Treeline shift

Treeline shift within the plots was evaluated by subtracting the elevation of the oldest position of the treeline (downslope) from the elevation of the present treeline within the plot (upslope). The oldest position of the treeline was estimated from the position of the tree in the plot having the oldest stem section at 2 m (Kullman 1986; Gamache and Payette 2005). Position of the present treeline was identified by presence of upper most upright tree with a minimum 2 m height (Liang et al. 2011). The age of the tree at 2 m height was determined by using the age difference between the base and the 2 m level (Shrestha et al. 2014). Number of years required by tree to attain 2 m level was calculated by using the age-height regression equation (Figure 3) (Liang et al. 2011). The total elevational advance of the treeline was converted to an annually averaged rate of advance to facilitate comparison between areas (Gamache and Payette 2005). Correlation and regression analyses were carried out to see the relationship between tree age and elevation. We used age of trees only in correlation and regression analysis, as advancing treeline would have younger trees in higher elevation. An advancing treeline would show a negative linear relationship (Paulsen et al. 2000; Bekker 2005; Kirdyanov et al. 2011).

1.6 Recruitment pattern

Recruitment pattern from the forestline to the species limit was studied by combining individuals from plots S1, S2, and S3 as south-, plots N1, N2, N3 as north-, and plot E as east- facing slopes. Individuals were distributed along the elevation gradient by putting percentage distance across ecotone for each individual (Elevation of individual - Forestline elevation/Treeline elevation - Forestline elevation) on the Y-axis and with establishment year on the X-axis. The location of uppermost tree in each aspect was identified by dividing establishment years into 50 years interval beginning from 1750, to see how treeline has changed historically. Uppermost location of the tree was identified within each 50 year interval zones and connected with each other to see the treeline advance trend.

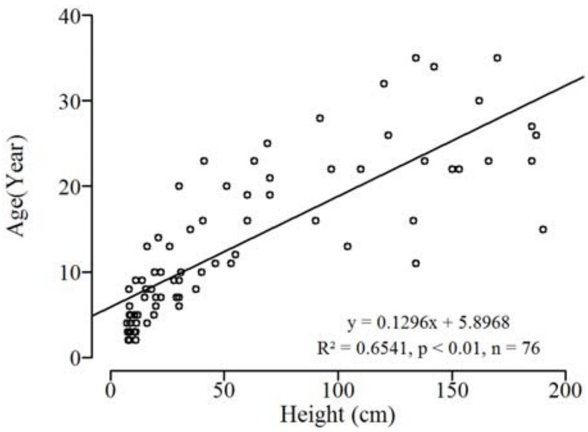


Figure 3 Correlation between age and height (76 cut samples). Cut samples are from 44 seedlings (Height: < 0.5 m) and 32 saplings (Height: 0.5-2 m).

2 Results

2.1 Treeline ecotone

Abies spectabilis covers all the studied slopes of Barun valley, and grows from the river valley

(3650 m) to upper treeline limit of 4092 m (east-facing slope), 4058 m (south-facing slope) and 3960 m (north-facing slope). All seven plots have distinct forestlines and treelines with the treeline ecotone length varying from 50 m to 235 m (Table 1). The vertical length of the treeline ecotone was shorter in south- and north-facing slopes than the east-facing slope due to moderate slope angle. Forestline, treeline and species limit were higher on the east-facing slope than the south- and north-facing slopes. The treeline form is a diffuse type because tree density decreases with increasing elevation (Harsch and Bader 2011).

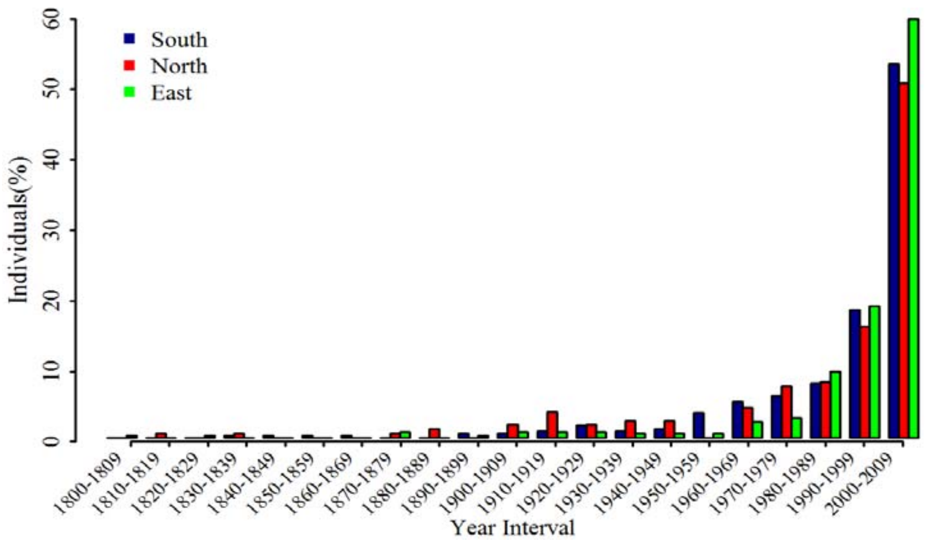


Figure 4 Age structure distribution (10 year interval) of *A. spectabilis* at the treeline ecotone of south-, north-, and east facing slopes Barun valley, eastern Nepal. Age structure for each slope was obtained by combining all data taken from the number of tree ring for the trees and the number of internodes for seedlings and saplings.

2.2 Age structure

Density of the trees was found to be 115 individuals/ha, saplings was 100 individuals/ha, and seedlings was 357 individuals/ha in south-, 67 individuals/ha, saplings was 44 individuals/ha, and seedlings was 174 individuals/ha in north-, and 108 individuals/ha, saplings was 151 individuals/ha, and seedlings was 495 individuals/ha in east-facing slopes. The age class distribution curves of all the slopes were reverse J-shaped (Figure 4). The age structure was dominated by individuals with younger age classes. Most of the trees were established before the 1980s, and age structure was dominated by saplings and seedlings at the latter stage. Individual established after 2000 formed the largest age class (53% of total individuals in south-, 50% in north-, and 59% in east-facing slopes). There was no significant difference in temporal pattern of recruitment in south and north-facing slopes (α = 0.05) according to Kolmogorov-

Table 2 Oldest and youngest established trees in seven study plots and treeline shift rate (SR)

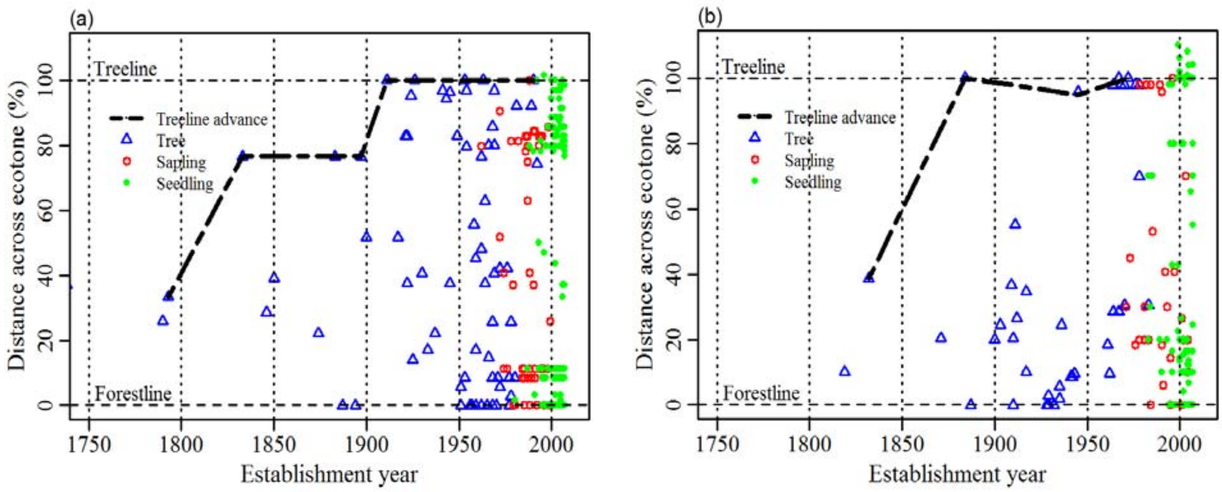
Plot	Rec-position	Old-position	Diff-position	Age-old	Age-rec	Diff-age	SR (cm/year)
S1	4058	4038	20	188	25	163	12.2
S2	4045	4030	15	145	52	93	16.1
S3	3969	3947	22	241	68	173	12.7
N1	3941	3911	30	146	11	135	22.2
N2	3960	3960	0	94	94	0	0.0
N3	3949	3940	9	160	7	153	5.9
E	4092	4034	58	211	18	193	30.1

Notes: Rec-position, Recent position of tree (m a.s.l); Old-position, Oldest position of tree (m a.s.l); Diff-position, Difference in position (m a.s.l.); Age-old, Age of oldest position tree (years); Age-rec, Age of recent position tree (years); Diff-age, Difference in age (years);
Column 2 is the recent position or upper most position of the tree within the study plot, Column 3 is the elevation of the oldest tree within the study plot, Column 4 is the difference in elevation between uppermost and oldest trees within the plot, Column 5 is the age of oldest tree within the plot, Column 6 is the age of uppermost tree within the plot, and Column 7 is the age difference between uppermost and oldest trees within the plot, and Column 8 is the shift rate calculated by using equation: *Difference in position (column 4)/Difference in age (column 8)*

Smirnov test. However, there was significant difference in temporal pattern of recruitment in south and east, and north and east facing slopes (α = 0.05).

2.3 Treeline shift

Treeline has shifted upward in all the plots except N2, which shows a stable treeline position over the last 94 years. Treeline has shifted upward in S1 plot by 20 m in last 163 years, 15 m in last 93 years in S2, 22 m in last 173 years in S3, 30 m in last 135 years in N1, 9 m in last 153 years in N3, and 58 m in last 193 years in E plots (Table 2). The treeline advance rate in S1, S2, S3, N1, N3, and E plots was 12.3 cm/yr, 16.1 cm/yr, 12.7 cm/yr, 22 cm/yr, 5.9 cm/yr, and 30.1 cm/yr (Table 2). Most recent trees within the treeline were established in 1989 (South), 1967 (North), and 1958 (East) (Figure 5). Treeline has advanced until the early 20th century and has been stable on all slopes since then (Figure 5). However, breaking down the treeline shift pattern in 50-year intervals indicated that treeline advanced until 1910 in south-, 1970 in north, and 1960 in east-facing slopes. No significant correlation was found between tree age and elevation on any of the slopes (p<0.01) (Figure 6).



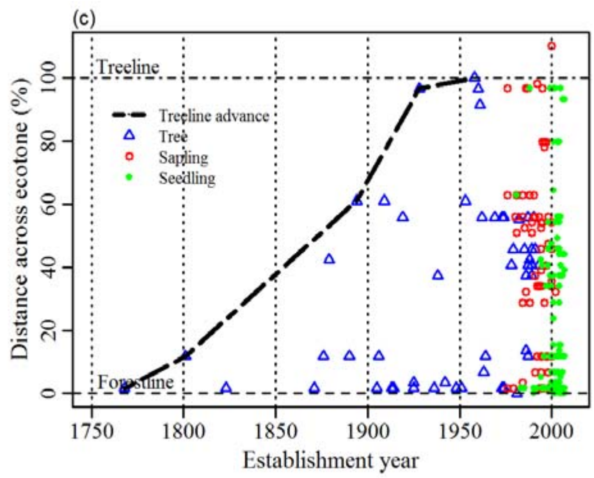


Figure 5 Recruitment pattern: (a) south - (after combing individuals from S1, S2 and S3 plots), (b) north - (after combing individuals from N1, N2 and N3 plots), and (c) east - facing (E plot) slopes. Distance across ecotone (%) was calculated by using following equation:

$$\frac{Elevation\ of\ individual\ (m\ a.s.l)-Forestline\ elevation\ (m\ a.s.l)}{Treeline\ elevation\ (m\ a.s.l)-Forestline\ elevation\ (m\ a.s.l)}.$$

2.4 Recruitment pattern

The oldest established tree dated back to 1790, 1833, 1738, 1832, 1884, 1819, and 1768 in S1, S2, S3, N1, N2, N3, and E plots, respectively, whereas youngest tree was established in 1970, 1989, 1992, 1978, 1962, 1978, and 1990 in S1, S2, S3, N1, N2, N3, and E plots, respectively. Analysis of the plots data indicated that, most of the trees were established in the early and middle of the 20th century in south-, north-, and east-facing slopes (Figure 5). Trees established in the second half of the 20th century were concentrated near the forestline area (Figure 5). Likewise, most of the saplings and seedlings were concentrated near the forestline, and a few individuals were present above the treeline. The number of seedlings and saplings above the treeline in all the slope was significantly less compared to that below the treeline.

3 Discussion

3.1 Treeline ecotone

The structure and composition of the treeline ecotone are influenced by aspect (Danby and Hik 2007) because south-facing slopes receive more solar radiation than north. In the Himalaya, natural treelines are at the higher elevation in south-facing slopes compared to north (Schickhoff 2005). Sometimes, the difference in the altitudinal position is up to several hundred meters (Schickhoff 2005). For example, in this study we recorded upper treeline in the south- and north-facing slopes at 4058 m and 3960 m, respectively, and treeline of south-facing slope was about 100 m higher than that of the north-facing slope. However, treeline of the east-facing slope was found to be higher than that of the south- and north-facing slopes in Barun valley. Moderate slope and high soil depth on the east-facing slope might be the possible reason for high treeline position. We could not establish more study plots on east-facing slope due to the short ectone length compared to south and north-facing slopes. Therefore, the single plot from east facing slope might not reflect the correct trend.

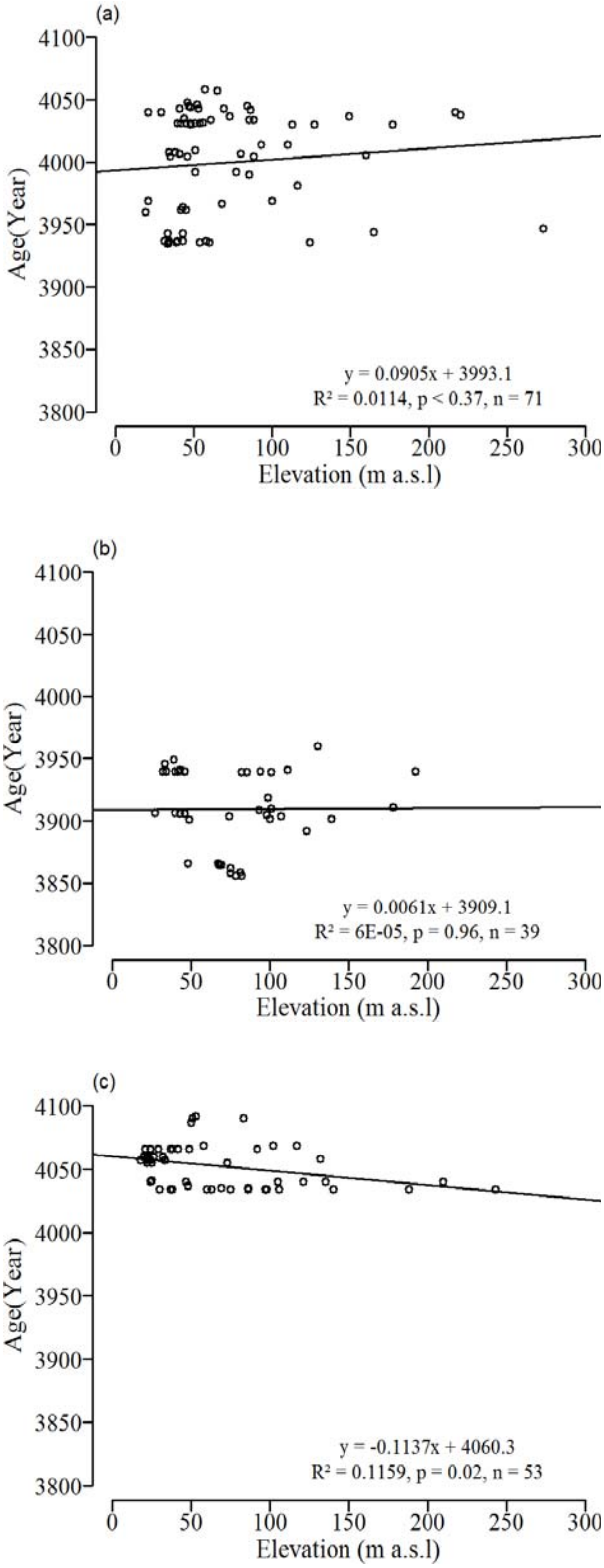


Figure 6 Tree age and elevation relationship: (a) south-facing, (b) north-facing, and (c) east-facing slopes.

3.2 Age structure

Temporal variation in recruitment pattern in response to climate change at the treeline ecotone may be studied by age structure (Zhao et al. 2012). Moreover, population structure of tree populations at treeline reflects the history of recruitment success and mortality event (Körner 2012). The age structure distribution pattern of *Abies spectabilis* indicated the recruitment and mortality pattern over time at the treeline ecotone of Barun valley. Age structure was dominated by the younger age classes (mostly seedlings less than 10 years old) with high mortality. Mortality was inferred from number of individuals present in age classes. Number of individuals was high in 1-10 years age class but this number decrease drastically to 10-20 year age class. This mean mortality of less than 10 years class is high, and only selected individuals are converting into higher age class. This was also verified by the low saplings density compared to seedlings. Most of the trees (86%) were established before 1980. This indicated that there was no major conversion of saplings into trees in recent decades during the favorable climate. However, the J-shaped age structure obtained in the Barun valley showed recruitment balanced with mortality through time, indicating a stable treeline position in balance with existing environmental condition (Dalen and Hofgaard 2005). Differences in the temporal recruitment pattern of the east facing slope with south- and north- facing slopes may be due to the limited sample.

3.3 Treeline shift

The simplest descriptor of an upward shift of an alpine treeline ecotone is the change in elevation at which the highest (altitude) tree is found (Liang et al. 2011). Treeline has risen in all the plots in Barun valley, except the N2 plot in north-facing slope, however significant elevational expansion was not observed since 1950. The average upward shift in treeline was recorded to be 22 ± 5.5 (SE) m in last 130 years, which was smaller than 200 m in 92 years in the Scandes, Sweden (Kullman and Oberg 2009), 300 m in 44 years in the western Himalaya (Panigrahy et al. 2010), and 30-50 m in 100 years in the northern Siberia (Kirdyanov et al. 2011). Moreover, younger trees at the higher elevation within the treeline ecotone are an indicator of treeline advance (Dalen and Hofgard 2005). In all plots and slopes of the study area, most of the high elevation treeline trees were found to be established before 1970, and recently established trees were concentrated near the forestline. Furthermore, no significant relation was found between tree age and elevation on south-, north-, and east-facing slopes. This showed that treeline position of *Abies spectabilis* has not undergone a significant elevational expansion in the Barun valley in recent time, in contrast to general expectation of treeline advance in response to global warming (Camarero and Gutrrez 2004). However, presence of significant number of individual that have established after 1950s above the forestline indicate the infilling of the treeline ecotone. Shrestha et al. (2014) also found that *Abies spectabilis* and *Pinus wallichiana* treelines of mesic and dry areas of central Nepal are stationary. Similarly, Liang et al. (2011) reported that *Abies georgei* treeline position has changed little in the last 200 year, despite warming on the Tibetan Plateau. Worldwide treelines (the Scandes mountain - Dalen and Hofgard 2005, the Tianshan mountains - Wang et al. 2006) also showed regionally deviating patterns and the evidence of treeline stability. Despite an overall warming trend in the Barun valley region treeline has not expanded significantly since 1950, and this might be due to the cold episodes which could have caused dieback of saplings and seedlings above treeline (Korner 2012). Analysis of the CRU 0.5° × 0.5° grid century long temperature data of the region indicated many cold periods in the region (Figure 2d).

3.4 Recruitment pattern

Another indicator of treeline advance is the presence of a considerable number of saplings and seedlings above treeline. They provide the potential for treeline advance in response to climate improvement (Hofgaard et al. 2009). The number of seedlings and saplings of *A. spectabilis* growing above treeline were almost negligible in the Barun valley in comparison to other mountains of the world such as the Swedish Scandes (Kullman 2004) and Finnish Lapland (Holtimer and Broll 2005), and Tibetan Plateau (Liang et al. 2011). Shrestha et al. (2007) also observed very low recruitment of *Betula utilis* above treeline in Manang, central Nepal. One reason for the absence of young individuals above the treeline is the high mortality of seedlings due to a closed shrubs canopy, where shading was excessive and light levels were too low to maintain a positive carbon balance (Johnson and Smith 2005; Wang et al. 2012). Richardson and Bond (1991), Hättenschwiler and Körner (1996) mentioned that competition with shrubs in the regeneration niche is main reason for the distribution limit of many *Pinus* species in the European Alps. Another reason is the lack of bare mineral soil surface. Exposed soil is more suitable for seed germination than shady *Rhododendron* spp. and *Junipers* spp. shrubs covered areas, which reduce the survival capacity of seedlings and saplings above treeline by blocking the sunlight. Natural (insect and pathogen attack) and anthropogenic disturbances (fire wood harvesting, herbivory, fire) would create canopy openings which enhanced seedlings emergence (Munier et al. 2010). Tree establishment above the present forestline would only be possible if warming coincided with canopy disturbance (Holtmeier and Broll 2007; Wang et al. 2012). Hättenschwiler and Körner (1996) have found that subalpine tree species such as *Pinus sylvestris* at the treeline ecotone regenerate only as a stochastic disturbances and gap formation. Such disturbance and gap formation activities were absent in the Barun valley. Moreover, fire, inter-annual variation in air temperature, topography, winter snow cover, abrasions and ecotone patterns (diffuse, abrupt) may also affect treeline dynamics (Camarero and Gutierrez 2004). Many studies such as Engelmark (1987) and Hättenschwiler and Körner (1996) have shown a correlation between lower abundance of treeline tree species above the current limit and fire frequency. Gap opening by fire or disturbance with warming might provide a better chance of upward migration to treeline tree species and this indirect effect might take several decades to detect (Hättenschwiler and Körner 1996). No records of fires (scar on tree ring, burn remnants) were observed in the study area. Therefore, observed low recruitment above treeline (Figure 5) supports the fact that there is no impact of temperature increase on the number of seedlings and saplings above the treeline.

Shrubs are the important dominant vegetation type above the treeline in Barun valley. The area above the treeline in south-facing slope is covered by dense *Juniper spp*., the north facing slope is dominated by *Rhododendron spp*., and the east facing slope is dominated by *Juniper spp*. and *Rhododendron spp*. A vigorous shrub belt above treeline may slow tree establishment (Körner 2012). The dense shrub belt above treeline, and the absence of tree seedling and sapling above the present treeline can be also explained by strong competitive ability of shrub communities in comparison to trees. In Barun valley, the annual variability in air temperature was observed to be high, which might be playing a major role in shaping the recruitment pattern. Therefore, until the general warming trend consistently exceeds inter-annual variability, treeline advance may depend upon the coincidence of favorable conditions over sufficient years to permit establishment, growth and survival (Szeicz and MacDonald 1995; Harsch et al. 2009; Wang et al. 2006). According to Paulsen et al. (2000) an advance of treeline could take place only if low-temperature events/periods which limit growth are so rare that they are insignificant. However, a few decades of warmer period may be too short for changes in recruitment pattern. For instance Hättenschwiler and Körner (1996) did not observe any change in population structure of *Pinus sylvestris* and *Pinus cembra* in Swiss Alps in spite of 0.8°C rise in temperature. Treeline position will always lag behind climate change by at least 50 to 100 years due to the recruitment lag, cold induced dieback, winter warming rather than summer, and strong competition from dense alpine heath (field layer plants above the treeline) (Körner 2012).

4 Conclusions

Treeline position is not undergoing a significant elevational expansion in recent decades in Barun valley, eastern Nepal with limited localized recruitment above the present forestline, despite the increased annual temperature trend in the region. Global warming alone would not necessarily result into the upward shift of treeline. Factors such as local topography, high shrub density, lack of disturbance, and high inter annual variation in air temperature might lead to counter effects impact of temperature increase on tree recruitment. The treeline would remain stable until some climatic threshold is reached, resulting in a favorable condition for more successful establishment. It is difficult to predict when this threshold will be reached. So, there are few chances of treeline advance in the near future in Barun valley, eastern Nepal.

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