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An overview of treeline response to environmental changes in Nepal Himalaya

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Abstract: Changes in treeline dynamicsare, considered reliable indicators of rapidly changing climate in Himalayan mountains. This paper is aimed at exploring treeline forming species in Nepal Himalaya, their growth-climate relationship and shifting response of climate change to improve our understanding on existing methodologies of treeline studies. It was found that the treelines in Nepal Himalaya are both temperature and moisture sensitive. The reconstruction of stand stage structure has been the common method of treeline studies in Nepal Himalaya; this showed site and species specific response to environmental changes. The recent stand densification and higher shifting rates are observed for *Abies spectabilis*, whereas both stand densification and shifting are slow for *Betula utilis.* There still exists a gap in knowledge regarding microtopography, soil properties, biotic interaction among species and influence of land use change with rapidly changing climate in the treelines of Nepal Himalaya.

Key words: Recruitment, regeneration, timberline, treeline, treeline shift.

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Introduction

Treeline in a broad sense refers to the ecotone representing the transition between timberline and the treeless alpine vegetation (Körner 2003); as the broad area of 50 to 100 m below the treeline to the line bounding the full forest (closed timberline forest) (Fig. 1). Since the timberline and treeline are coupled boundaries, the fundamental mechanisms causing their general position is considered to be similar (Körner 1998).

Treelines are widely used as an indicator for observation of landscape response to climatic change. The life and growth form of trees change sharply due to the severe climate at the upper edge of mountain forests, and form at least four types of treelines; diffuse, abrupt, island, and krummholz 'Diffuse treeline' is characterized by a gradual decrease in the height and density of trees; 'abrupt treeline' is a continuous forest of > 2 m tall trees directly bordering low alpine vegetation, trees may be present above a continuous forest but their presence is infrequent; clumped patches or linear strips ('fingers') of krummholz or trees above the continuous forest limit forms the 'island treeline'; and severely stunted or deformed multi-stemmed trees occurring in clumped patches above the upright forest forms a 'krummholz treeline', also referred to as krummholz-island treelines (Harsch & Bader 2011).

The highest elevation treeline in northern hemisphere is formed by *Juniperus tibetica* Kom in south west of Tibet at 4900 m asl (Miehe *et al.* 2007). Temperature is described as the main influencing abiotic factor to delimit the elevation of alpine treeline and to constrain the growth and regeneration of tree species in treelines (Harsch *et al.* 2009; Holtmeier & Broll 2007; Körner 2003). The germination of seeds and seedling recruitments in treeline ecotones are limited because of thermal deficiency and soil moisture scarcity, particularly in inner ranges. Given the repeated climatically caused treeline fluctuations during the Holocene (MacDonald *et al.* 2000; Reasoner & Tinner 2009)

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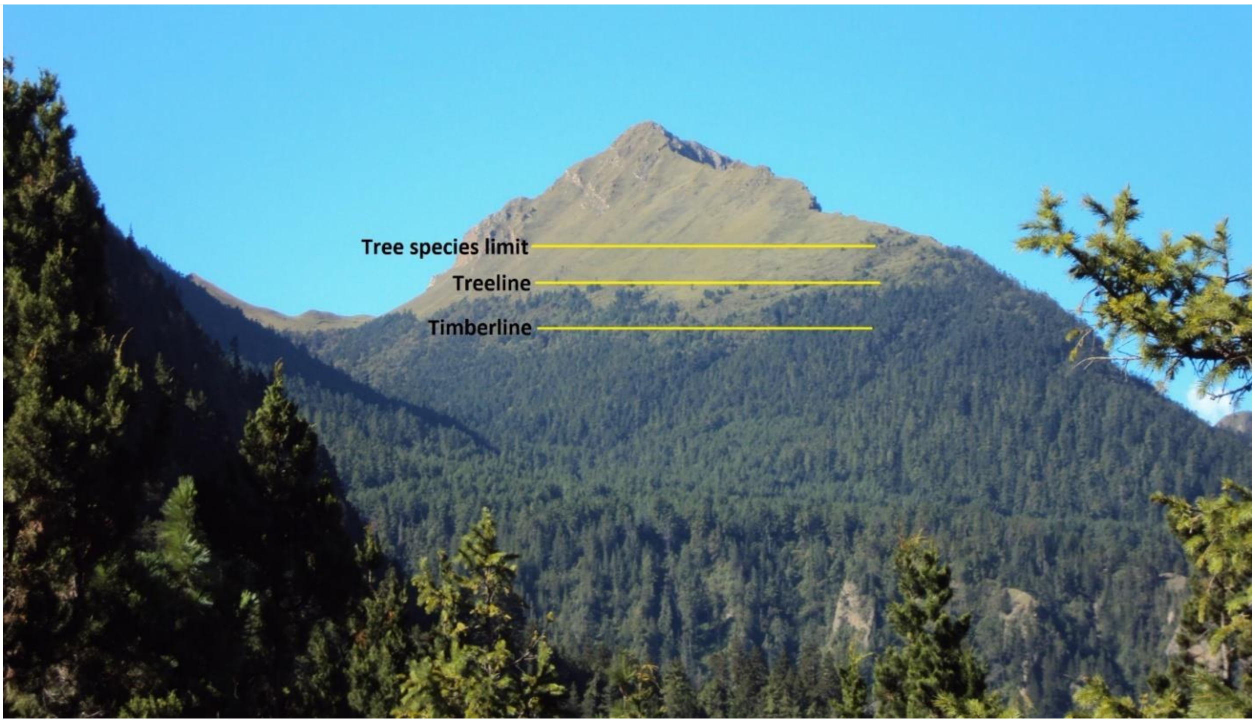

Fig. 1. Position of tree species limit, treeline and timberline in a sub alpine forest (Marche, Mustang Nepal) (Photograph by A. Tiwari, 2014).

and the general dependency of the upper limit of tree life on thermal balance, it seems apparent that climate warming will improve growth conditions of treeline forest stands, generate higher stand densities and induce treelines to advance to higher elevations (Dullinger *et al.* 2004; Grace *et al.* 2002; Smith *et al.* 2009). And, there is increasing evidence that rate of climate warming is amplified by elevation and latitude (IPCC 2014; Huang *et al.* 2017; Pepin *et al.* 2015). As a consequence, the polar and high elevation treelines are generally shifting upward in response to global warming despite their complex ecology and dynamics (Grace *et al.* 2002; Harsch *et al.* 2009; Holtmeier & Broll 2007; Jobbagy & Jackson 2000; Kullman 2001; Liu *et al.* 2002; Malanson 2001; Payette 2007).

Physiographic factors including soil moisture at different slopes may exert remarkable variation in the spatiotemporal patterns of regeneration, tree establishment, and stand density at upper treelines (e.g. Daniels & Veblen 2004; Elliott & Kipfmueller 2011), and the related patterns differ between slope aspects due to the differential presence of permafrost (Danby & Hik 2007; Elliott & Kipfmueller 2010). Besides, interaction among species has also been found to be the important factor on modulating altitudinal treeline dynamics (Liang *et al.* 2016; Schwab *et al.* 2017).

Himalayan mountain system is often rugged terrains, hence the regional distribution of temperature and precipitation is greatly varied even over short geographic distances (Schickhoff 2005; Tiwari *et al.* 2017b). Due to this, a higher spatial heterogeneity in elevation of treelines and their regeneration dynamics is expected. Upper timberline trees should primarily move upslope in the mountains due to warming, owing to the altitudinal temperature gradient, as has been frequently documented during the recent decades (Gottfried *et al.* 2012; Kelly & Goulden 2008). The mountains usually have conical shape; hence the upslope movement inevitably results in range loss and may even lead to 'mountain-top extinctions' (Colwell *et al.* 2008) in extreme cases. Hence treeline dynamics of ecotone would also supplement the existing knowledge on the future of mountain top species and their distribution range. This article gives an overview of treeline forming species, climatic trends, growth limiting factors and treeline dynamics representing the treeline sites studied in Nepal Himalaya (Fig. 2). The existing methodologies and rate of treeline shifting in the region have also been evaluated.

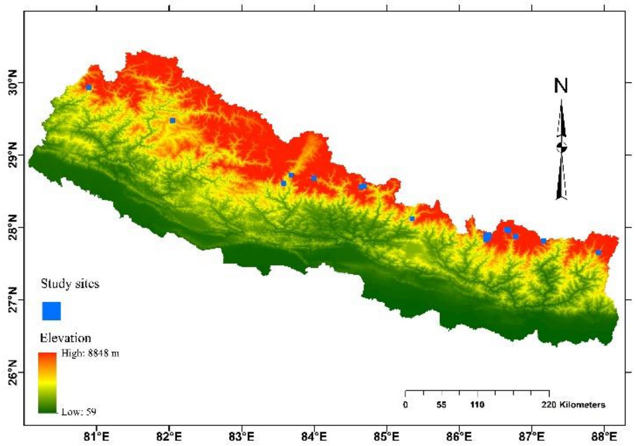

Fig. 2. Map of Nepal showing treeline sites explored.

Research methods to detect changes in treelines

The common methodological practices of monitoring treeline shifting involve monitoring, recruitment patterns of trees in identified plots, reconstruction of stand age structure, the use of historical aerial photographs (Baker & Moseley 2007), and an analysis of remotely sensed data. In northwestern Yunnan (Hengduan Mountains), several sets of historical photographs showed that shrubs were encroaching into alpine meadows and treeline showed substantial shifting in elevation (Baker & Moseley 2007; Moseley 2006). However, an upward altitudinal shifts in treelines could be due to the cessation of pastoral use and other human disturbances than the climatic change. Besides, treeline dynamics can also be monitored using images from remote sensing satellites, which helps to overcome the difficulties posed to direct observation by the poorly accessible Himalayan terrain (Rawat 2012).

From Himalayan region stand age structure and recruitment pulses are only studied in order to describe treeline dynamics. However, there still exist differences in quantification of inertia of treeline, which mainly involve non-uniformity in procedure and outpost tree response, besides the challenging task of disentangling the climatic and anthropogenic impact on treeline formation.

Treeline forming species in Nepal Himalaya

The most common species in terms of distribution and exploration in Nepal is *Abies spectabilis* (Table 1). Plot based studies to explore treeline dynamics have been conducted on only few species (*Abies spectabilis, Betula utilis, Pinus wallichiana, Rhododendron campanulatum*) are included so far. *A. spectabilis* and *B. utilis* treelines are shown in Fig. 3 as typical example from Nepal.

Climatic trends in Nepal Himalaya

The summer season is dominated by a south-westerly flow from the Bay of Bengal, which pushes moist air masses into the eastern Himalayas leading to summer precipitation up to 3000 mm in mountains in general, but up to 5000 mm on the windward Himalayan slopes in central Nepal. The winter climate is determined by a uniform westerly flow leading to occasional precipitation events, particularly in the western Himalaya (Böhner 2006; Maussion *et al.* 2013). Hence the eastern Himalaya receives about 80% of the annual precipitation during summer, and the far western parts receive up to 50% of the annual precipitation during winter. Himalayan region sustains mainly dry conditions throughout the transition season, although infrequent convective precipitation is common at south facing slopes (Romatschke *et al.* 2010).

Great variation in elevation and topography have distinctly modified regional and local climate of treelines in Nepal Himalaya. The precipitation pattern at the local-scale is mainly influenced by wind- and leeward positions furnished by topography and local scale circulation patterns (Gerlitz *et al.* 2014). Studies showed that the rate of future mid-latitude warming will be enhanced at higher elevations in comparison to the surrounding landmass at the same latitude, particularly in the colder seasons (Pepin *et al.* 2015; Rangwala *et al.* 2013), hence high mountain regions are particularly sensitive to climatic changes. More rapid changes in high-mountain climates would have consequences far beyond the immediate mountain regions, as mountains are 'water towers' and the major source of water for large populations in downstream and they are critical to people and ecosystems (Christensen *et al.* 2007).

Himalayas are warming at higher rates than global average rate of 0.74 °C during the previous century. In high elevation areas of Himalayas, the warming rate is reported to be between 0.6 and 1 °C decade^{-1} (Shrestha *et al.* 1999). Elevation and bias-adjusted ERA-Interim reanalysis and spatial high-resolution temperature trends over the Himalaya for the period since 1989 showed that the winter season maximum temperature trends of up to +0.8 °C decade^{-1}. Similarly, the pre-monsoon season

Table 1. Treeline forming species in Nepal Himalaya.

Species, distribution range (m asl)	Species characters	Remarks
Abies spectabilis (3000–4000 m)	Dominant tree in the central and western Himalaya, grows better on cool and moist north facing slopes. It commonly occurs as a canopy dominant species, accompanied by different species of *Rhododendron* as well as *Betula utilis* (Chhetri 2008).	Most explored species in treeline in Nepal Himalaya
Betula utilis (2700–4300 m)	Only broadleaved angiosperm tree species in the Himalaya which dominates an extensive area in subalpine altitudes (Zobel & Singh 1997), and forms tree line vegetation all along the Nepal Himalaya (TISC 2002)	Only a broadleaved tree forming treeline in Nepal Himalaya
Pinus wallichiana (2000–3600 m)	Found in temperate to sub-alpine zones, typically in mountain screes and glacier forelands, the highest altitude records of 4400 m in *Pinus-Betula* woodlands of Dolpa (Miehe *et al.* 2015)	Forms treeline in relatively drier regions such as Trans-Himalaya like Manang (Shrestha *et al.* 2014)
Juniperus spp. (3700–4400 m)	*J. indica* is found in upper montane coniferous forest and woodland in pure stands, or with e.g. *Abies, Pinus, Cupressus torulosa*, or in *Betula utilis* subalpine woodland, to alpine heath and grassland and into the bare moraines and scree of the niveous zone. *J. recurva* has the highest record of a tree in Nepal at 4400 m (Miehe *et al.* 2015)	*J. indica* reported from upper treeline on sunny slopes of Mustang, 3,600 m, 28°53'N/83°45'E (Miehe *et al.* 2015). *J. recurva* at highest elevation in Khumbu valley.
Quercus semecarpifolia (1700–3800 m)	Evergreen oak of the middle cloud forest belt of the Central Himalaya with moderate monsoonal rainfall, montane climax forest. Those reaching the upper treeline on southern exposures have snow deformed trunks.	Reported in the form of abrupt treeline in western Nepal (not verified)
*Rhododendron campanulatum** (2800–4400 m)	Major understory component of sub-alpine forest, and forms pure stand above treeline in Nepal Himalaya (Polunin & Stainton 1997; Rajbhandari & Watson 2005).	Regeneration dynamics studied in Nepal (Rana *et al.* 2017)

*Shrub forming krummholz plot based regeneration dynamics studied in Nepal

maximum temperature trends were also found to be increasing for the entire Himalayan Arc. The warming trend has subsequently decreased frost days (up to –17 days decade) in the Nepal Himalaya, with substantial increase of growing degree days for the southern slopes of the Himalaya at elevations between 2000 and 3500 m (Gerlitz *et al.* 2014).

Negative trends of annual precipitation (up to 20% for the previous century) were reported over the western Himalaya (Bhutiyani *et al.* 2010; Duan *et al.* 2006; Jain *et al.* 2013). Long-term trends of winter precipitation rates are slightly negative but not statistically significant (Bhutiyani *et al.* 2010). The enhanced frequency of winter and pre-monsoon drought events since the early 1980s has been particularly reported for western Nepal Himalaya (Panthi *et al.* 2017; Wang *et al.* 2013). However, eastern Himalaya has shown no change in annual precipitation (Jain *et al.* 2013). The warming in high mountains in the central Himalaya is mainly due to substantial increase of day temperature (Tmax), and some regions are experiencing decreasing trend of mean minimum temperature (Tmin) (Rana *et al.* 2017; Tiwari *et al.* 2017b). Both increasing (Tiwari *et al.* 2017b) and decreasing trends (Rana *et al.* 2017) of rainfall have been

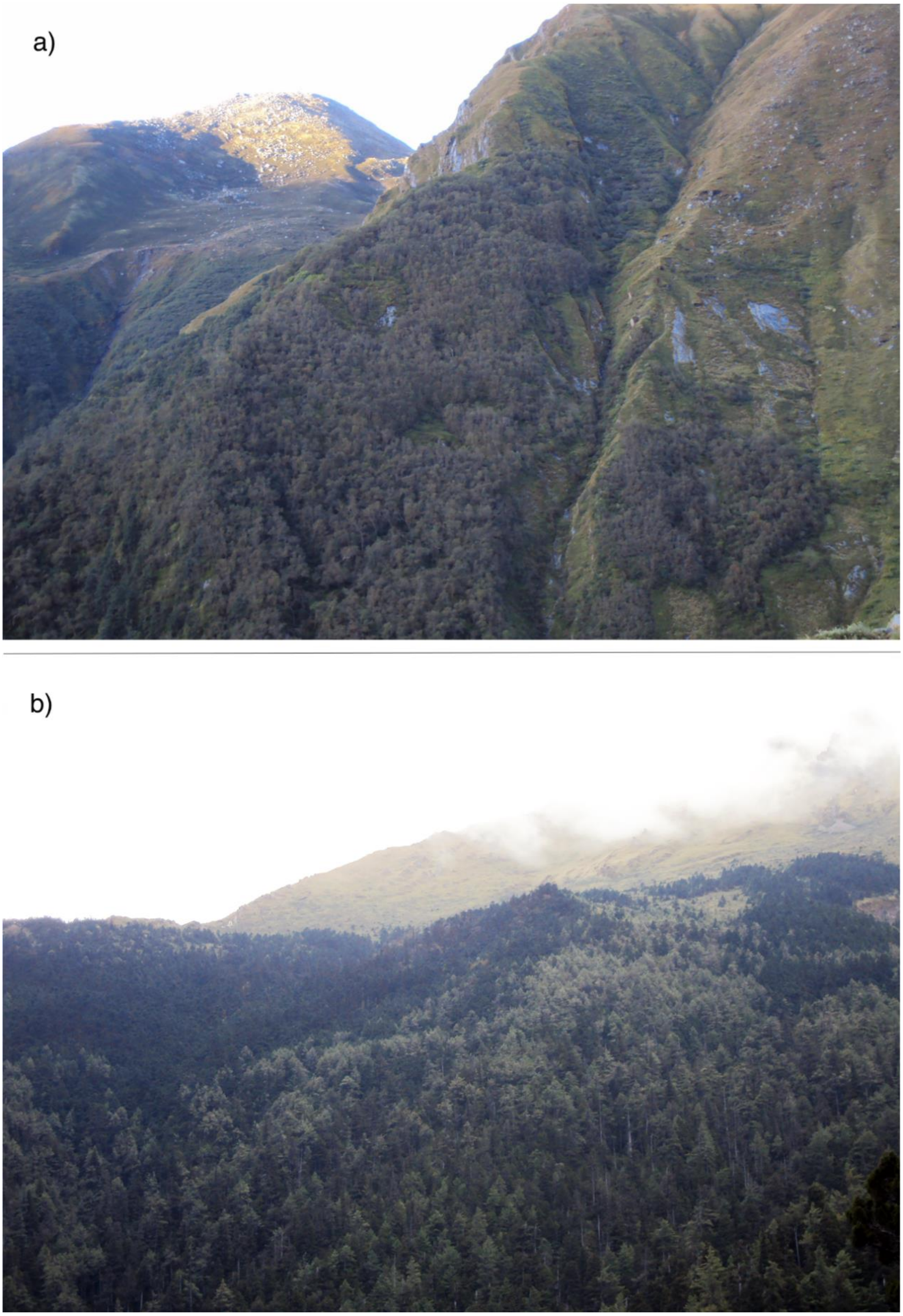

Fig. 3. Treeline ecotones in Mustang: *Betula utilis* treeline site at Kokhedhara (Lete) (a), *Abies spectabilis* treeline site at Chimang (b) (Photograph by A. Tiwari, 2014).

observed. The rising temperatures associated with increasing evapotranspiration rate and decrease of precipitation over the Himalayas likely to intensify drought stress, particularly in the pre-monsoon (early growing) season (Liang *et al.* 2014; Panthi *et al.* 2017; Tiwari *et al.* 2017b). The intensified pre-monsoon droughts may suppress tree growth and seedling recruitments.

Growth-climate relationship

Growth–climate analysis is performed by correlating annual ring width index chronologies and climate data. Climate in the preceding growing season has a strong influence on tree growth in the following year (Fritts 1976). The growth period includes previous year's growing season, intervening winter/spring and the growing season during the year of ring formation, which includes an evaluation of any effects of preconditioning by climate before the growing season (Biondi & Waikul 2004; Cook & Kairiukstis 1990).

Studies in Himalayan region indicated that the limiting factors for tree growth in the treeline are temperature as well as moisture. The observation of moisture sensitive treelines from some parts of central Himalaya indicated both topographic complexity and regional climate variation in the region (Miehe *et al.* 2015). The highly elevated maximum temperature (Tmax) in the higher elevations induces moisture stress due to evapotranspiration, and increases drought sensitivity of high mountain trees (Tiwari *et al.* 2017b). Generally, in Himalayan treelines, the snow cover lasts for more than 4 months (5–6 months also), however, it is now being affected by warming, which can have a considerable influence on seedling establishment, and overall treeline dynamics. In some cases the slightly increasing mean annual temperature has still not responded promptly to treeline shift although the higher rate of shifting has been observed after 1950 (Suwal *et al.* 2016). Responses to warming in terms of radial growth of trees have been found to differ between conifers and broadleaved species (Gaire *et al.* 2016).

Site selection constraint

Treeline studies associated with dendrochronological techniques are greatly limited by site selection. The natural and near natural treelines are often inaccessible and difficult to access due to higher field expedition costs, hence treeline studies from natural ecotones are very rare, and so called near natural treelines are often exposed to anthropogenic disturbance. The orographic treelines are highly complex in terms of growth climate relationship and population demography including seedling recruitment. Most treelines in the southern slope of entire Himalayan region are anthropogenic as stated by Schickhoff (2005).

Site-specific regeneration

Intensive studies on seedling establishment and tree recruitment intreeline ecotone are scanty, so tree recruitment patterns in the treeline ecotones are not well understood (Dutta *et al.* 2014; Schickhoff 2005; Schickhoff *et al.* 2015, 2016). Most of the studies refer to stand age structure and population demography of treeline ecotones at the given time. The regeneration studies in treelines of Nepal Himalaya show reverse J-shaped density–diameter distributions, and good regeneration, which may result in an upward movement of treeline (Gaire *et al.* 2011, 2014; Ghimire & Lekhak 2007; Ghimire *et al.* 2010; Shrestha *et al.* 2007; Sujakhu *et al.* 2013; Suwal *et al.* 2016). In some regions, however, rather bell-shaped density–diameter distributions or deviation from reverse J-shaped distributions (Lv & Zhang 2012; Sujakhu *et al.* 2013) were observed indicating poor regeneration.

Some demographic studies have not included the smallest dbh class (Ghimire & Lekhak 2007; Shrestha *et al.* 2007); they only showed smaller numbers than the subsequent larger class (Gaire *et al.* 2011, 2014; Sujakhu *et al.* 2013), which could be misleading because the smaller seedlings emerge into trees in few years time. The lower frequency of the small dbh class recorded in some investigations may indicate grazing impact. The lower numbers of the tall diameter classes or absence of classes above 50 cm dbh (Ghimire & Lekhak 2007; Gaire *et al.* 2011, 2014; Sujakhu *et al.* 2013) also indicated substantial anthropogenic impacts in high mounatins.

In Nepal Himalaya most of the treeline studies are confined to single tree species in the ecotone (Gaire *et al.* 2014; Lv & Zhang 2012; Shrestha *et al.* 2007; Sujakhu *et al.* 2013). Studies also found that some near-natural treeline ecotones can also contain codominant tree species which respond differently to climatic changes (Trant & Hermanutz 2014). Changes in tree physiognomic characters (diameter at breast height (dbh), tree height and growth form) in treeline are highly sensitive to decreasing temperature both air and soil resulting in climatically shaped growth forms (Holtmeier & Broll 2005). Thus, multispecies approach to survey all ecotone tree species to detect their sensitivity to environmental changes could be the future research issue in treeline ecotone.

Few studies from Nepal provide data on recruit densities. In Langtang valley, Gaire *et al.* (2011) found significantly low *B. utilis* recruits per ha, about the same number of *A. spectabilis* and significantly less *R. campanulatum* and *S. microphylla* recruits compared to the ecotone in Rolwaling. Schickhoff *et al.* (2015) found a comparable distribution of seedling and sapling species and slightly higher total numbers of recruits in Langtang. Recruit density of *Pinus wallichiana* was very high (c. 4500 ha^{-1} at lower altitude; c. 1000 ha^{-1} at higher altitude) in Manang (Ghimire *et al.* 2010). This is consistent with its colonizing habit. A study on *A. spectabilis* from Manang also exhibited very high recruit numbers (c. 3200 ha^{-1}). However they found a very high number of *A. spectabilis* recruits at relatively lower altitudes (3500–3900 m asl; c. 5600 N ha^{-1}) in comparison to higher altitude (3900–4200 m asl; c. 160 ha^{-1}). *Pinus wallichiana* showed a similar pattern with high numbers at lower and smaller numbers at higher altitude. The poor regeneration at the higher elevation indicated more or less stationary position of treeline in these sites. The poor regeneration was also observed for *R. campanulatum* (c. 200 ha^{-1}, Sujakhu *et al.* 2013) and for *A. spectabilis* in Barun valley (c. 200 N ha^{-1}; Chhetri *et al.* 2016).

In summary, the site and species specific regeneration and tree establishment have been found along treeline in Himalayas. Usually recruitment of birch in the closed forest canopy is lower than that of pine and fir. The recruit height class distribution of *A. spectabilis* was found to be different from *B. utilis*, *Acer caudatum* and *Sorbus microphylla*. Obviously, the last species grow faster and aggregate more individuals in taller height classes at the early life stage.

The occurrence of trees at the upper edge indicated that there is a potential to develop even further. The frequency of survivors of new recruits for *A. spectabilis* and *B. utilis* towards higher side of elevational ranges was reasonably high, indicating their upslope migration. Open canopy favors the growth of birch and pine whereas fir regenerates well in closer canopies. In many Himalayan treelines stand densification in the recent decades has been observed (Chhetri *et al.* 2016; Shrestha *et al.* 2014; Tiwari *et al.* 2017a); similar results were observed from south east Tibet (Liang *et al.* 2011). The influence of warming climate on regeneration as well as treeline shifting is evident in some regions including Himalayan region (Camarero & Gutiérrez 2004; Wang *et al.* 2006)

Treeline shifting in central Himalaya

There are a few actual field observations on treeline shift in the Himalayas, and they show that the species responses to recent climatic change vary: (i) substantial upward shifting (Gaire *et al.* 2014, 2016; Tiwari *et al.* 2017a); (ii) moderate upward shift (Chhetri *et al.* 2016); and (iii) almost stationary treeline position (Gaire *et al.*2011; Liang *et al.* 2011; Schickhoff *et al.* 2015; Shrestha *et al.* 2014); and even the possibility of retreating in case of warming induced drought stress (Liang *et al.* 2014). Several studies have revealed that there has been rapid densification of treeline ecotone in the recent decades indicating the possibility of treeline shifting to upper elevation in near future (Gaire *et al.* 2014; Shrestha *et al.* 2007; Tiwari *et al.* 2017a).

Treeline dynamics appear to be more related to changes in snow precipitation than to global warming (Negi 2012). Remote sensing investigations (Singh *et al.* 2012) indicated an upward shift of treeline up to 80 m in the Uttarakhand Himalayas, between 1962 and 2009. Similar reports were made from northwest Yunnan, with rapid glacier recession. The dramatic increase in vegetation cover, drastic reduction of snow cover and upward shifting of alpine plants have also been reported in the central Indian Himalayas (Panigrahy *et al.* 2010).

Most of the treeline ectones studied for quantifying treeline shift in Himalaya constitute younger forest stands, as observed from reconstruction of stand age structure. There has also been non-uniformity in considering treeline and calculating treeline shift. Most of the studies rely on Gamache & Payette (2005) using the following formula:

$$\text{Rate of shift (per yr)} = \frac{\text{Uppermost elevation of young tree} - \text{Uppermost elevation of oldest tree}}{\text{Age of oldest tree} - \text{Age of youngest tree}}$$

Some studies followed horizontal stretch (1.5 km) crossing the respective elevation transects to find the mean position of treeline. The average elevation of these treelines gave mean treeline of that location (Dalen & Hofgaard 2005; Shrestha *et al.* 2014). This method eliminates the influence of single outpost tree while locating the exact treeline of the given area. However, in most of the studies in Nepal Himalaya, treeline is considered as the highest

Table 2. Treeline studies from central Himalaya in Nepal.

Location	Region	Species	Elevation (m asl)	Lat/Long	Reference	Limiting factor
Rolwaling	central	fir	3900	27.86°N, 86.41°E	Schwab *et al.* (2017)	species interaction
Mustang (Dry)	central	fir	3641	28.72°N, 83.68°E	Tiwari *et al.* (2017a)	moisture
Mustang (Moist)	central	birch	3900	28.6°N, 83.58°E	Tiwari *et al.* (2017b)	moisture
Rolwaling	central	fir	3900	27.9°N, 86.36°E	Müller *et al.* (2016)	soil moisture
Manaslu	central	fir	3950	28.57°N, 84.65°E	Gaire *et al.* (2014)	temperature
Pangboche SNP	eastern	fir	≈ 4000	27.87°N, 86.78°E	Gaire *et al.* (2016)	temperature, moisture
Dole SNP	eastern	fir	≈ 4000	27.97°N, 86.65°E	Gaire *et al.* (2016)	temperature, moisture
Phorste SNP	eastern	birch	≈ 4000	27.96°N, 86.68°E	Gaire *et al.* (2016)	not specific
Ngawal Manang	central	pine	4067	28.68°N; 84.00°E	Shrestha *et al.* (2014)	season specific
Lauribinayak, Rasuwa	central	fir	3824	28.12°N; 85.35°E	Shrestha *et al.* (2014)	season specific
Samagaun (MCA)	central	fir	3701	28.56°N, 84.69°E	Suwal (2010)	temperature (recruitment)
MCA	central	fir	3858	28.57°N, 84.69°	Suwal *et al.* (2016)	land use
GCA	central	fir	3956	27.89°N, 86.37°E	Suwal *et al.* (2016)	land use
Barun valley	eastern	fir	4092	(27.81°N, 87.16°E	Chhetri *et al.* (2016)	winter temperature
Ghunsa (Kanchanjungha)	eastern	birch	4118	27.65°N, 87.92°E	Bhuju *et al.* (2016)	unknown
Chuchhemara (Rara)	western	fir	3870	29.47°N, 82.05°E	Bhuju *et al.* (2016)	unknown
Api Nampa	far-west	fir	≈ 3700	29.93°N, 80.89°E	Bhuju *et al.* (2016)	moisture

elevation at which at least a single upright tree with height greater than 2 m as mentioned by Hofgaard (1997) and Körner (2003). The following table (Table 2) summarizes the treelines explored in Nepal Himalaya.

The stand densification by young individuals in the treeline indicated that juveniles could be more benefitted by warming temperature, whereas adult trees will have more competition for water (Lv & Zhang 2012; Qi *et al.* 2015). Investigations on the differences in variables explaining adult and juvenile population densities of different life stages and their relation to abiotic and biotic conditions are required to understand regeneration dynamics in treeline ecotone. Early beginning of growth season and warmer maximum temperature have increased rate of evapotranspiration and hence moisture stress in Nepal Himalaya (Laing *et al.* 2011; Panthi *et al.* 2017; Tiwari *et al.* 2017b). Because of this, in drier areas (Trans-Himalaya, central Nepal) decline in growth of birch has been observed (Tiwari *et al.* 2017b).

While we concentrate on natural treelines, it is critically important to understand the interaction between climate change and altered land use (Vittoz *et al.* 2008) to assess the potential for treeline advance beyond the current climatically determined upper limit. It is reported that prolific regeneration, increased tree establishment and invasion into treeless areas above the anthropogenic forest limit, are directional changes readily attributed to effects of climate change. However in most cases, pastoral abandonment or other changes in human impact also influences

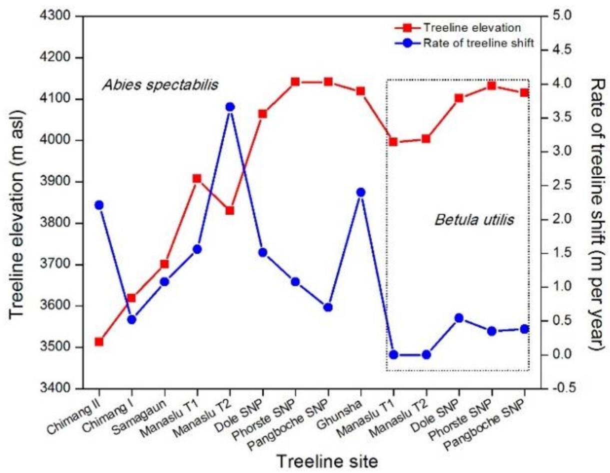

Fig. 4. Treeline elevation and rate of shifting in Nepal Himalaya (rate of shifting is expressed as zero in sites with no shifting and in the sites where shifting was not studied).

treeline dynamics (Holtmeier 2009; Schickhoff 2011); excessive grazing pressure, widespread fire (Beug & Miehe 1999), seasonal drought and poor quality of soil (Müller *et al.* 2016) were reported as the main agents for lowering treelines in Himalaya.

The observed treelines across Nepal Himalaya show that the treeline elevation is higher in the eastern sites in comparison to the western sites (Figs. 2 & 4) as mentioned by Bhuju *et al.* (2016). This spatial variation could be due to the different rainfall patterns in eastern and western sites; however there has not been investigation on it. The rate of upward shifting showed that *A. spectabilis* is shifting faster than *B. utilis* in most of the sites, and there are very few studies on growth performance of these species from the same region. The variation on rate of shifting could be due to the different regeneration behavior, seed dispersal mechanism and water utilization strategies of these species in treelines. Also *B. utilis* is distributed at higher elevation (reaching up to glaciers) in Nepal Himalaya and poor regeneration of this species at treelines could be due to the lack of soil substrate, poor soil conditions (Müller *et al.* 2016) and greater slopes above existing treelines.

Conclusion

Most findings on advancing treelines in Nepal Himalaya show considerable recruitment of seedlings and saplings in the recent decades especially after 1950s. There has not been the reporting of retreating treelines in the region, although some treelines have remained stationary (Gaire *et al.* 2016; Shrestha *et al.* 2014). Soil environment in Himalayan treelines is highly critical for tree recruitment, however as mentioned by Müller *et al.* (2016) such studies are rare in the region. Increased biotic interaction in the treeline ecotone sometimes, outweighs the climatic influence on tree establishment (Liang *et al.* 2016; Schwab *et al.* 2017). Given the rapid warming (maximum temperature trend) in the Himalayan treelines, warming induced drought stress is the most visible impact in association with prolonged early growing season (March–May) drought (Dawadi *et al.* 2013; Liang *et al.* 2014; Panthi *et al.* 2017; Tiwari *et al.* 2017a,b) with strong influence on regeneration in treeline ecotone. Changes in land use patterns, pastoral abandonment, less disturbance in high mountain forest (migration of people to lower valleys) as well as expanding protected area in Nepal Himalaya have greatly modulated treeline dynamics in region. The stand densification by younger individuals could also be the part of succession process in treeline ecotone besides environmental influence. Therefore long term monitoring of forest stands in treeline is immensely important while interpreting treeline dynamics. Further, the lack of long term environmental history (temperature, rain, cloud cover, snow) in the region has made past distribution range of high mountain forests more enigmatic. Further studies focusing on environmental factors, microtopography, soil factors, growing season shift as well as reproductive performance and seed dispersal mechanisms in the treeline are essential to scale up our existing knowledge on treeline dynamics in the Himalayan region.

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