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STUDY OF TREELINE ECOTONE TO ASSESS LONG-TERM IMPACT OF ENVIRONMENTAL CHANGE IN MT. EVEREST REGION, NEPAL HIMALAYA

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Abstract

Treeline is an excellent bioindicator of climate change impacts on high altitude biota. However, very few studies on the biological impacts of climate change have been reported from Nepal due to the lack of baseline information. This study of treeline ecotones in Mt. Everest region, Nepal Himalaya aims to prepare baseline information on structure and position of treeline to monitor the response of the ecotone to environmental change. This study was carried out at three treeline sites of Sagarmatha (Mt. Everest) National Park, in eastern Nepal Himalaya. Two to four belt transect plots (size: 20m wide, 100-190m long) were laid in each sites which included treeline as well as tree species limit. The present position of treeline with associated tree species composition was recorded and the position of each tree was mapped. Tree species in the site were represented by *Abies spectabilis*, *Betula utilis*, *Juniperus recurva*, *Rhododendron campanulatum*, *Salix* sp. and *Sorbus microphylla*. Irrespective of the sites, *R. campanulatum* was found growing at the highest elevation followed by *S. microphylla*, *A. spectabilis* and *B. utilis*. The population density ranged from 83 to 400 plants/ha with average density of 27 and 127 plants/ha for *Abies* and *Betula*, respectively. Size class distribution revealed an inverse-J shaped to multimodal bell shaped (DBH and Height) distribution indicating a situation of continuous to sporadic regeneration depending on the species and sites. As the size-class distribution graphs presented different shapes for different species and different sites, it is concluded that there exists a dynamic nature of the treeline ecotones and the species have site-specific and species-specific regeneration conditions. This study is expected to make a reference baseline for long term monitoring of treeline ecotones.

Introduction

Rapidly occurring environmental change including climate change has many bio-physical impacts, including shifting in geographic ranges, seasonal activities, migration patterns and abundances of species, and species interactions (Root *et al.*, 2003; Chen *et al.*, 2011; IPCC, 2014). An alpine or polar treeline is the one of the most obvious vegetation boundaries that limits regional tree growth (Holtmeier, 2009; Körner, 2012). The position of an alpine climatic treeline is mainly formed due to strong growth limitation by low-temperature conditions (Körner, 1998; Körner and Paulsen, 2004; Holtmeier, 2009) among several other factors. Natural treeline ecotones are sensitive biomonitors of past and recent climate change as they respond the climate change by exhibiting variations in position, structure and composition (Camarero and Gutiérrez, 2004; Holtmier and Broll, 2005; Harsch *et al.*, 2009; Kullman and Öberg, 2009; Kirilyanov *et al.*, 2012; Körner, 2012; Gaire *et al.*, 2014).

The Himalaya, as compared to other regions, are more sensitive to environmental changes because of rapidly changing climate and associated impacts (Shrestha *et al.*, 2012; IPCC, 2013, 2014). Vulnerability of ecosystems in the Himalaya to climate change is compounded by fragile topography and human activities, so prediction of future climate change impacts is complicated (Ferrarini *et al.*, 2014). There is a vast knowledge gap on various aspects of treeline formation and their dynamics in the Himalaya (Schickhoff, 2005; Dutta *et al.*, 2014). Available few studies from the treelines from Himalaya have reported increased tree density as well as an upward movement of the tree species limit (Dubey *et al.*, 2003; Gaire *et al.*, 2011, 2014).

The Sagarmatha (Mt. Everest) National Park (SNP), a natural world heritage site, is an important place due to its unique topographical, cultural and biological significance. However, the area is widely affected by climate change with several known impacts including shrinkage of permafrost areas (Fukui *et al.*, 2007), rapid recession of glaciers, formation and or increased size of glacial lakes (Fujita *et al.*, 1998; Bolch *et al.*, 2012; Thakuri *et al.*, 2014). Impacts on biological processes like range and distribution shift including treeline dynamics are also expected but studies on these aspects are limited (Bhujju *et al.*, 2010; Ferrarini *et al.*, 2014). In addition to the impacts of climate change, forest and biodiversity of the region is also influenced by anthropogenic activities (Byers, 2005; Garbarino *et al.*, 2014). In order to assess the impact of climate change and other anthropogenic activities in the natural biological community and predict their future distribution, it is very essential to know the current status of the forest and vegetation. Therefore, in this study, we aimed to (i)

ascertain the present position of upper forest, treeline, and species limits, and (ii) record the species composition and characterize the stand structure of treeline ecotones in SNP.

Materials and Methods

Study Area: Established in 1976, SNP occupies an area of 1,148 km² and is extended from 2,845 m (at Jorsale) to 8,848 masl (top of the Mt. Everest) (Bhujju *et al.*, 2007). It is the country's first national park that was included in UNESCO list of World Natural Heritage Sites in 1979. In the north, SNP is linked with the Qomolangma National Nature Preserve of Tibet and extends to the DudhKosi River in the south. Most of the park area is very rugged and steep terrain cut by deep rivers and glaciers. The park, as an ecological entity in the highest region of the world, is scientifically very unique and offers opportunities for multiple aspects of research in a natural laboratory.

The climate in Sagarmatha region has extreme contrast between the humid southern slope influenced by the Indian summer monsoon and arid valleys in the northern slope under the desiccation effects of the Himalaya. About 80% of the annual precipitation occurs in the monsoon season (June to September) and rest of the year is fairly dry. Precipitation is low as the park is in the rain shadow of the Karyalung-Kangtega range to the south. Annual precipitation is 984 mm in Namche Bazar (Elevation 3,440 m) and it decreases with the elevation and comes around 516 mm per year at 5050 m at Pyramid lab (Jha, 2010; Thakuri *et al.*, 2014).

Land cover classification shows that large area of land in the SNP is barren land (65.6%) most of it is above 5000 m, and less than 10% is forested area (Salerno *et al.*, 2010). Six of the 11 vegetation zones described by Dobremez (1972) for the Nepal Himalaya are represented in the park: upper-temperate (2501- 3000 m), lower sub-alpine (3001- 3500 m), upper sub-alpine (3501 - 4000 m), lower alpine (4001- 4500 m), upper alpine (450 - 5000 m) and Nival (above 5000 m) (Bhujju *et al.*, 2007).



Fig.1. Location map of the study area and study plots in the Sagarmatha National Park, Nepal Himalaya

Field visit and data collection: For this study, the treeline is defined as the high elevation region up to where 2 m tall trees can be found, and the species limit is defined as the highest position to which seedlings, saplings, or trees of the tree species are present.

Fieldwork was carried out during May-June in 2012 and 2013. After careful observation in transect walk at the treeline ecotones of three sites of SNP namely Pangboche, Dole and Phortse, the upper species limits of *A. spectabilis* and *B. utilis* in each site were ascertained. Two to four altitudinal transect plots (20m wide and 100-

190 m long) were marked at each sites in area where the treeline ecotones were as natural as possible. The plots were oriented with their longer side parallel to the maximum slope and covered the current species limit and treeline ecotone (Fig.1). The transect plots at the Dole, Phortse and Pangboche treelines were named as D1 and D2, PH1 and PH2, and P1 to P4, respectively. The aspects of the sampling site cover north-east, north-west and North facing slopes (Fig. 1). The length of the plots was determined based on the site conditions and distribution of the plants in the ecotones to capture the site characteristics of the area in our sampling. Individual plants were categorized and enumerated into three height classes: trees (>2 m), saplings (0.5-2 m) and seedlings (<0.5 m) (Wang *et al.*, 2006; Gaire *et al.*, 2011).

Census survey was carried out in each plot to count the number of all individuals except *Rhododendron campanulatum* individuals. For every individual, their geographic location in the plot (latitude, longitude, and altitude using Garmin e-trex GPS); size (diameter at breast height (DBH), height), growth form and species were recorded. The regeneration condition was determined by observing size class distribution (Wangda and Ohsawa, 2006; Lv and Zhang, 2012). The treeline dynamics was analyzed by observing the position of trees, saplings, and seedlings as well as the size class distribution. Various descriptive statistics (Average, SD, max, range) were calculated in the Microsoft excel and SPSS software.

Results and Discussion

Species composition and geo-referenced treeline position: Treeline ecotones of the study area were formed by almost the same species with slight variation between different aspects. In Panboche, the treeline was formed by *Abies spectabilis*, *Betula utilis*, *Juniperus recurva*, *Rhododendron campanulatum* and *Sorbus microphylla* while in Dole and Phortse *Salix* sp. has also been recorded in addition to the previous five species. The treeline of the north and north-west facing slope of the Langtang National Park is formed by same tree species (Gaire *et al.*, 2010) as in the north to north east facing in Manaslu Conservation Area (Gaire *et al.*, 2014) where *J. recurva* and *Salix* sp are not present. In addition to *Abies* and *Betula*, the *Quercus semecarpefolia* also forms treeline community in the western Himalaya (Rai *et al.*, 2012). Broadly, the treelines of the Himalayas are formed by deciduous species like *Betula* and *Larix*, and evergreen species like *Abies*, *Juniperus*, *Picea*, *Pinus* and *Rhododendron* (Miehe *et al.*, 2007).

Table 1 presents the position of tree and species limit of the major treeline forming species i.e. *A. spectabilis* and *B. utilis*. From the field exploration in Dole it was found that *A. spectabilis* species limit was at 4123 m asl (27° 51' 27.4'' N and 86° 43' 43.3'' E) in D1 and 4141 m asl (27° 51' 39.8'' N and 86° 43' 50.1'' E) in D2 while *A. spectabilis* tree limit was found at 4105 masl (27° 51' 31.6'' N and 86° 43' 47'' E) in D1 and 3996 masl in D2. In both transects the seedlings and saplings are at higher elevation than that of adult individuals. In D2 transect (190 m long) only seedling and sapling individuals of the *Abies* were recorded. *Betula* tree and species limit at Dole was found at same elevation i.e. 4103 m asl (27° 51' 31.6'' N and 86° 43' 47'' E) in D1 and 4132 m asl (27° 51' 40.3'' N and 86° 43' 50'' E) in D2. No *Betula* seedling was recorded in the plots. *Betula* species limit was lower than that of *Abies*. In D2, large numbers of *Sorbus*, *Salix* and *Rhododendron* individuals compared to other two species were recorded.

Abies spectabilis tree limit at Phortse was found at 4062 masl (27° 51.46' N and 86° 44.859' E) in PH2 while *Abies* was absent in PH1. *Betula* tree and species limit was found at 4099 m, asl (27° 51.483' N and 86° 44.936' E) and 4102 m, asl (27° 51.477' N and 86° 44.925' E) in the PH1. *Betula* species limit was higher than that of *Abies* in Phortse. Irrespective of the plots, *A. spectabilis* species limit (Elv. 4141 m asl 27° 51' 0.5'' N and 86° 47' 54.6'' E) was at higher position than its tree limit (Elv. 4134 m asl, 27° 51' 3.7'' N and 86° 47' 58'' E) in Pangboche while *Betula* species and tree limit was at lower elevation than *Abies* limit. The variation in the position of the species limit and treeline of *A. spectabilis* might be due to variation in the aspect and topographic condition as well as its recent dynamics. The position of *S. microphylla* in SNP was higher than that of *Abies* and *Betula* in most of the sites. Similar trend was observed in Langtang and Manaslu region (Gaire *et al.*, 2010, 2014).

Table 1. Position of treeline and species line of *Abies spectabilis* and *Betula utilis* in Sagarmatha National Park, eastern Nepal Himalaya.

Tree/species limit	<i>Abies spectabilis</i>			<i>Betula utilis</i>		
	Dole	Phortse	Pangboche	Dole	Phortse	Pangboche
Species limit(m asl)	4141	4064	4141	4132	4102	4115
Tree limit (masl)	4105	4062	4134	4132	4099	4115

The position of the treelines are the result of the interactions of several biotic and abiotic factors (Holtmeier, 2009; Körner, 2012), so their position and species composition varies across the world or within a region (Körner, 1998; Miede *et al.*, 2007). In Nepal, the treeline position varies between the eastern, central and western region with decreasing trend from east to west (Schickhoff, 2005). Generally, the upper treeline elevations in the Hindu Kush-Karakoram-Himalaya (HKH) region increases along NW-SE gradient and a peripheral-central gradient from the Himalayan southern slope to the Great Himalayan range and the Tibetan highlands (Schickhoff, 2005). Along the western slope of Mt Annapurna, the upper timberline (*B. utilis*, *R. campanulatum*) at north-facing slopes rises to 4000-4100 masl and to even 4400 masl on the Nilgiri northern slope (Schickhoff, 2005). However in the Kalchuman Lake area of Manaslu, *A. spectabilis* treeline was found at 3907 masl and the *B. utilis* treeline at 4003 masl (Gaire *et al.*, 2014) while at the Lauribinayak of Langtang *Abies* treeline was observed at about 3900-3950 masl (Gaire *et al.*, 2011, Shrestha *et al.*, 2015).

Community structural parameters of treeline forming species

Table 2. Population density of the treeline forming species in Sagarmatha National Park, eastern Nepal Himalaya

SPECIES	Population density (plants/ha)				Average
	Dole		Phortse		
	D1	D2	PH1	PH2	
<i>Abies spectabilis</i>	57	14	0	35	27
<i>Betula utilis</i>	19	8	210	270	127
<i>Juniperus recurva</i>	7	0	0	30	10
<i>Sorbus microphylla</i>	0	100	15	40	39
<i>Salix</i> sp.	0	69	0	25	24
<i>Total density</i>	83	191	225	400	225

The treelines we investigated are not monospecific but always mixed. Population density varies within and between sites and species. The average population density found was 225 plants/ha which ranged from 83 to 400 plants/ha. The average *A. spectabilis* density (27 plants/ha) was lower than that of *B. utilis* density (127 plants/ha) because the treeline site of the Phortse was dominated by birch trees. In this total population density, *R. campanulatum* is not included therefore plots density will be increased if we include it. The tree density in a treeline of Panboche area is higher than present record (Bhujju *et al.*, 2010). Similarly, in a study along the timberline ecotones (3100-3400 masl) in Kedarnath Wildlife Sanctuary, western Himalaya, Rai *et al.* (2012) found the total tree density ranged from 340 to 780 trees/ha. The density of the *A. spectabilis* recorded in this study is low as compared to the density observed in other treelines like Pangboche in SNP (Bhujju *et al.*, 2010), Lauribinayak in Langtang (Gaire *et al.*, 2011), Kalchuman area of Manaslu Conservation area (Gaire *et al.*, 2014) and Western Himalaya of India (Rai *et al.*, 2012). Average *Betula* population density in present study is lower than treelines in Pangboche, SNP, Lauribinayak, Langtang and Manang (Shrestha *et al.*, 2007). However, population density of *Betula* in Phortse was higher than that observed in the Pangboche by Bhujju *et al.* (2010) and Langtang (Gaire *et al.*, 2010). The *Betula* density of present study is lower than pure birch timberline but higher than mixed subalpine and timberline area of western Himalaya (Rai *et al.*, 2012). The variation of this population density might be associated with the variation in the topoclimatic conditions, elevation of the plots and growing/succession stage of the treeline in the different regions of the Nepal Himalaya (Schickhoff, 2005; Shrestha *et al.*, 2007; Rai *et al.*, 2012).

Size class distribution: Distributions of the various structural parameters like plant height, basal diameter, DBH were studied. Figures 2 to 5 show distribution of the DBH and heights of the tree individuals in Dole region. The average height of *A. spectabilis* at Dole was 1.63 m \pm 1.73 SD. Since maximum height was observed to be 5.5 m, the small average height indicates dominance of lower heights individuals' i.e. seedlings and saplings. Similarly, the average height of *B. utilis* was found 4.51 m \pm 3.38 SD. This indicates that the minimum presence of seedlings and saplings of *B. utilis*. The average DBH of *A. spectabilis* at Dole was 11.14 cm (SD = 5.74 cm, max = 20 cm) and DBH of *B. utilis* was 22.58 cm (SD = 19.8 cm, max = 76.0cm). The average DBH and height of *A. spectabilis* was lower than *B. utilis* indicates that there is lack of small sized

Betula individuals. The average DBH and height of *A. spectabilis* was higher in D1 while that of *B. utilis* was found to be high in D2 (Fig. 2 and 3).

From the study it was found that the average heights of *A. spectabilis* at Phortse was 3.53 m (SD = 2.95 m, max = 8.0 m). Similarly, the average height of *B. utilis* was found 5.12 m (SD = 1.65 m, max = 7.6 m). The average DBH of *A. spectabilis* and *B. utilis* at Phortse was 17.33 cm (SD = 6.45 cm, max = 29 cm), 9.24 cm (SD = 4.61 cm, max = 28.0 cm) respectively. The average DBH and height of *A. spectabilis* was lower than *B. utilis* indicating presence of young individuals of *Abies*. The *A. spectabilis* was absent in the PH1 transect.

The average DBH of *Abies* in Dole and Phortse was lower than that observed in the Pangboche area of the SNP as well as treelines of the Langtang (Gaire *et al.*, 2011) and Manaslu (Gaire *et al.*, 2014). This might be due to the young growing condition as well as low population density. However, average DBH of *B. utilis* in Dole was higher than that observed in the treeline of the Pangboche area of SNP and area Kalchuman Lake area of Manaslu (Gaire *et al.*, 2014) and but lower than Langtang (Gaire *et al.*, 2010).

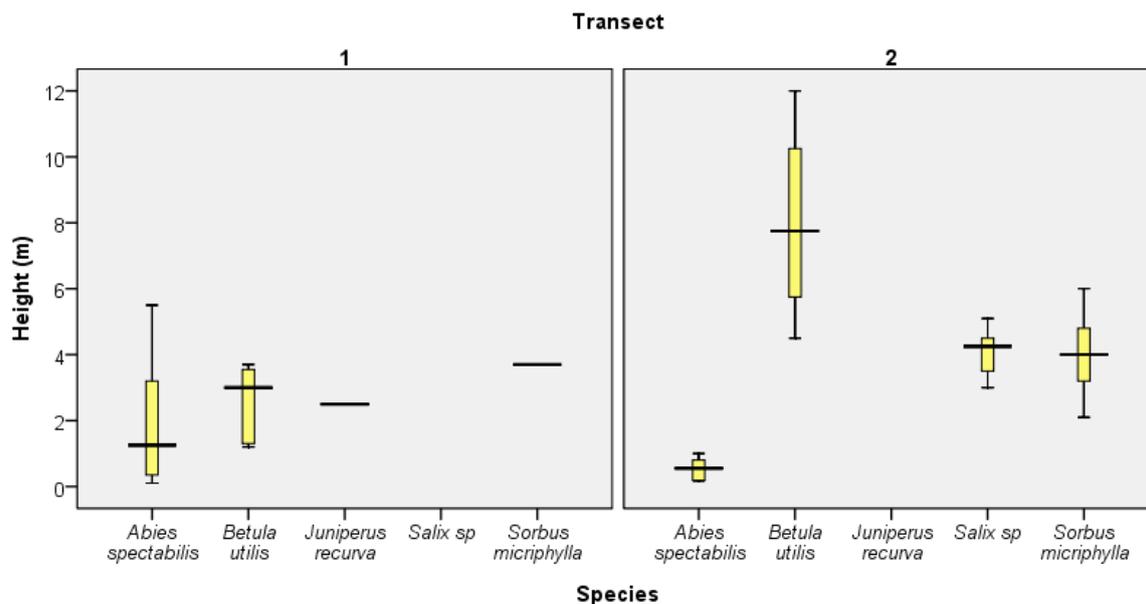


Fig. 2.Box and whisker plot of tree height in Dole, Sagarmatha National Park, eastern Nepal

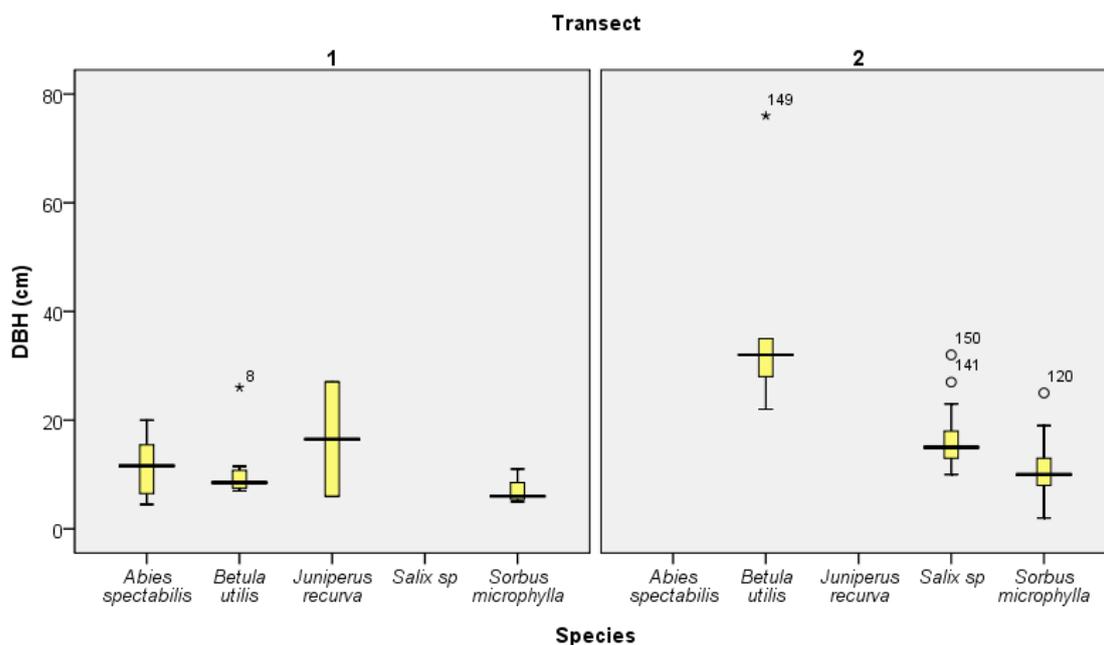


Fig. 3. Box and whisker plot of DBH tree species in Dole, Sagarmatha National Park, eastern Nepal.

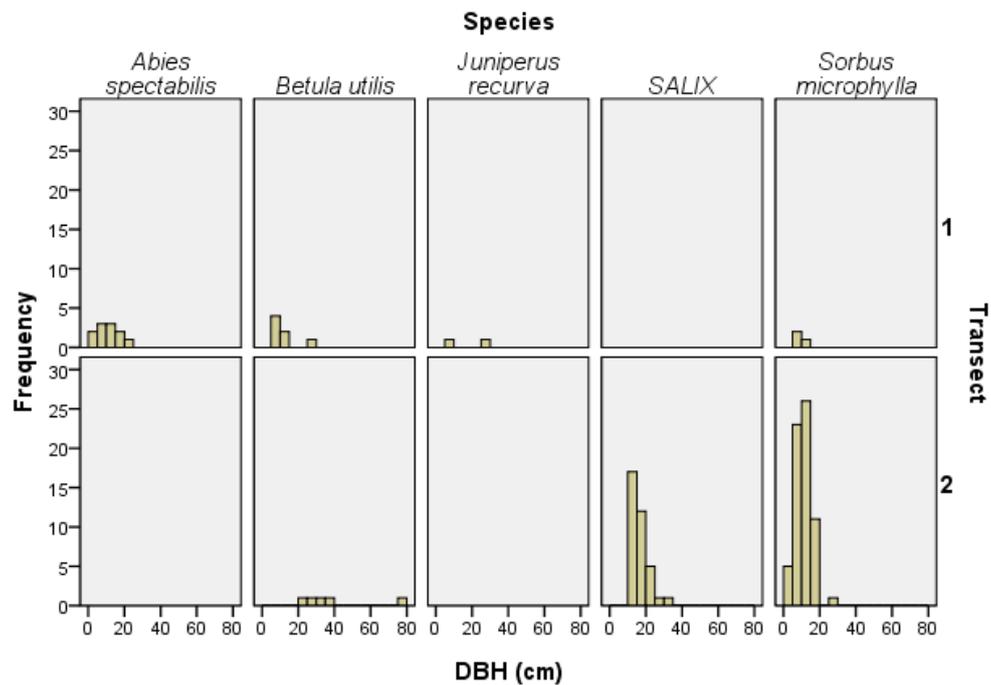


Fig.4. DBH class distributions of major tree species in Dole, Sagarmatha National Park, eastern Nepal

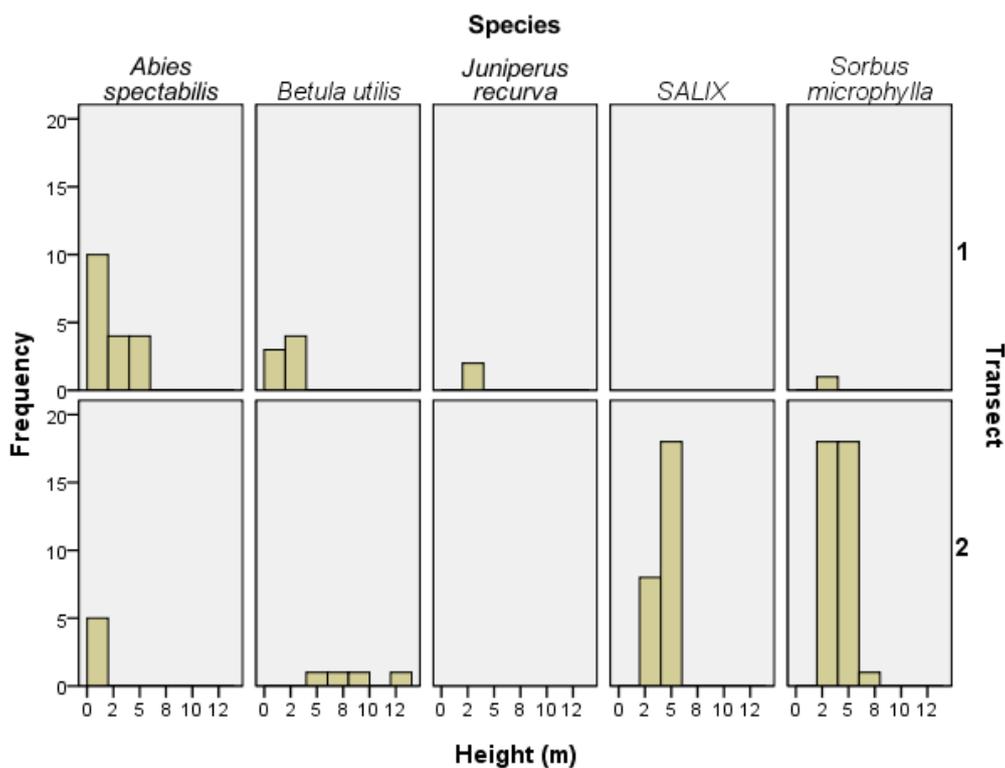


Fig.5. Height class distribution of tree species at Dole, Sagarmatha National Park, eastern Nepal

The box plot depicted a skewed distribution of the treeline forming individuals (Figs.3 and 6) indicating differential regeneration status of these species. Figure 4 presents the DBH class distribution in Dole. The DBH distribution of *A. spectabilis* shows unimodal bell shaped distribution in D1 with peaks at 5-15 cm. However, all individuals in D2 were smaller than breast height. DBH distribution of *B. utilis* in D1 is slightly similar to the inverse-J shape. However, DBH distribution of same species in the D2 shows sporadic pattern. Height class

distribution includes all individuals and shows that there is better regeneration of *A. spectabilis* than *B. utilis* in recent years with slightly an inverse-J shaped distribution of *Abies* and bell shaped or sporadic type distribution of *Betula* (Fig. 5). Similar trends were observed in height class distribution. In case of *A. spectabilis* height class 0-2 m had highest number of individuals indicating recruitment of individuals in recent years.

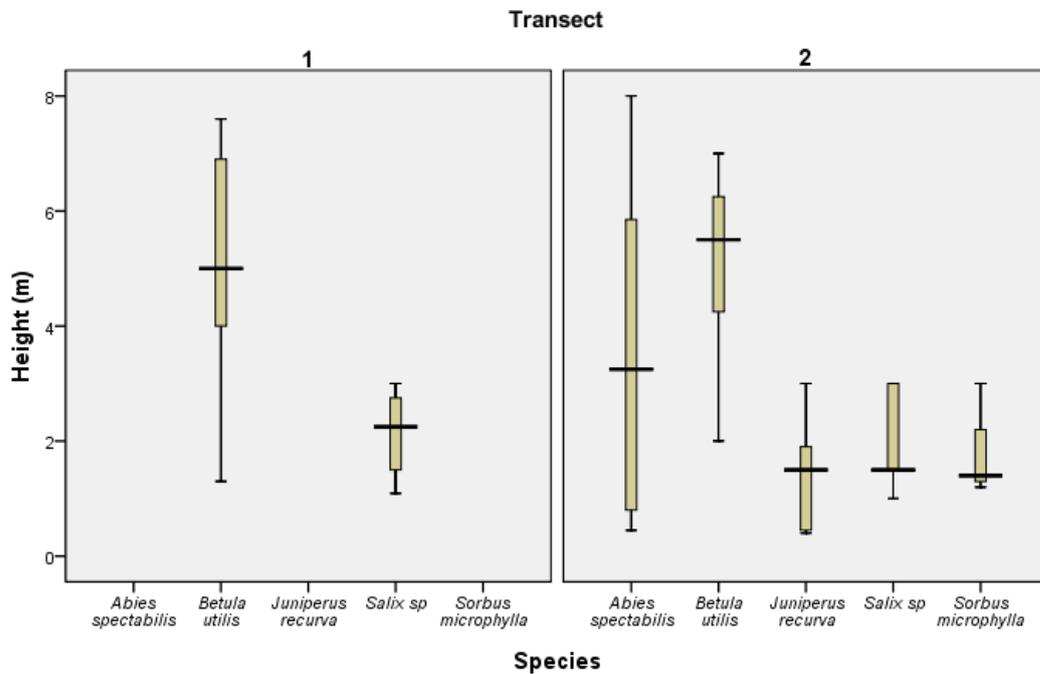


Fig. 6. Box and whisker plot of DBH of tree species in Phortse, Sagarmatha National Park, eastern Nepal

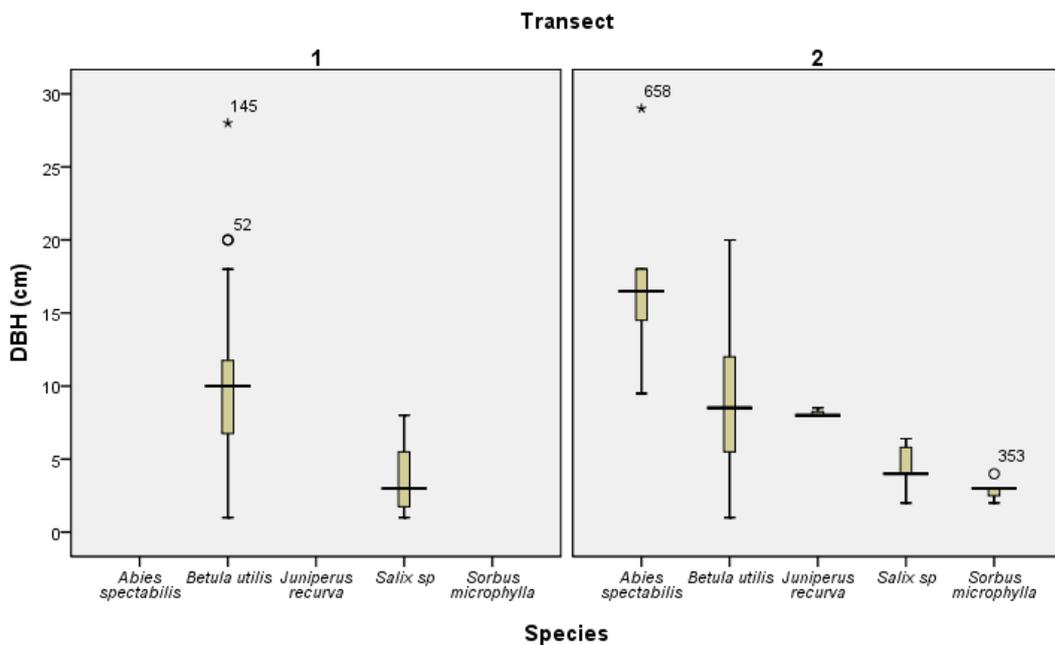


Fig. 7. Box and whisker plot of tree height in Phortse, Sagarmatha National Park, eastern Nepal

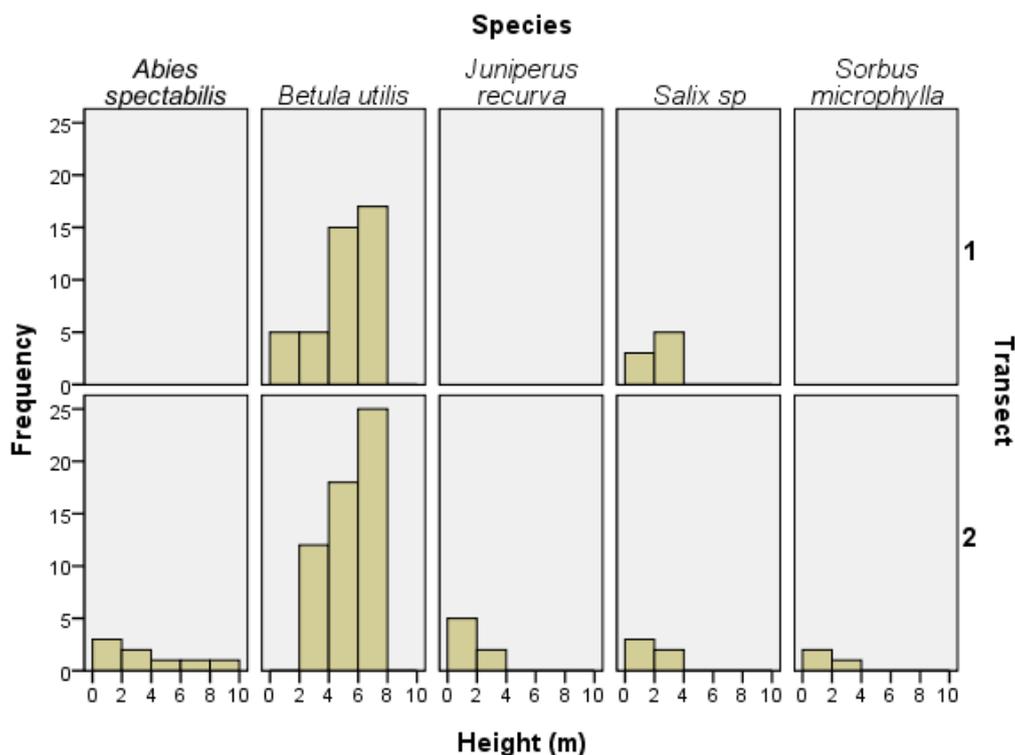


Fig. 8. Height class distribution of tree species in Phortse, Sagarmatha National Park, eastern Nepal

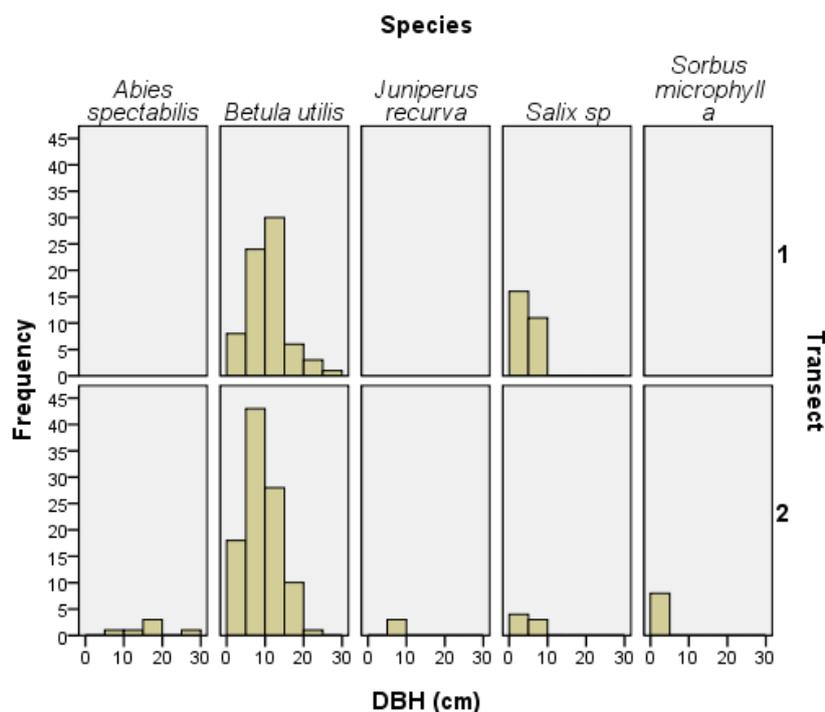


Fig. 9. DBH class distribution of tree species in Phortse, Sagarmatha National Park, eastern Nepal

Figures 6 to 9 show the distribution of the DBH and heights in Phortse. The distribution is asymmetric in shape indicating differential regeneration condition in the area. The DBH class distribution of *A. spectabilis* shows slightly unimodal distribution in the PH2 with peaks at 15-20 cm (Fig. 9); however, it was absent in PH1. DBH class distribution of *B. utilis* in PH1 is slightly unimodal with peak in 10-15 cm. The same species in the PH2

shows slightly an inverse-J shaped pattern indicating good regeneration compared to PH1. The height class distribution of *Betula* shows its growing stage. From overall analysis, it seems that the recent regeneration of *Abies* is good as compared to that of *Betula*.

The size class distribution of the tree species reflects its regeneration status (Wangda and Ohsawa, 2006; Lv and Zhang, 2012; Liang *et al.*, 2011; Rai *et al.*, 2012). In our study, the structural parameters not only varied between the plots but also between the species with the shape of DBH distribution from an inverse-J shaped to uni-to multi-modal bell shaped. In a study in treeline of Manaslu, the DBH class distribution of *A. spectabilis* shows a unimodal to bimodal distribution (Gaire *et al.*, 2014). Such kind of differences in the DBH class distribution of *A. spectabilis* and *B. utilis* have been observed in other treeline ecotones in Nepal (Shrestha *et al.*, 2007; Bhujy *et al.*, 2010; Gaire *et al.*, 2011) and Indian Himalaya (Rai *et al.*, 2012), indicating site-and species-specific regeneration condition. Similarly at the *A. spectabilis* treeline near the Everest region on the Tibetan side, Lv and Zhang (2012) observed a multimodal DBH distribution with peaks 0-10 and 30-40 cm. The differential spatio-temporal regeneration pattern reflected in the multimodal size of age and/or DBH class distributions were also observed in various treelines sites of different mountains (Wang *et al.*, 2006; Gou *et al.*, 2012). The regeneration at the treeline can be sporadic or episodic (Cuevas, 2002; Lv and Zhang, 2012). The gaps in some diameter and height classes observed in the present study indicate that episodic regeneration during the favorable climatic period is the most common feature even in these treeline ecotones.

Conclusions

The present study provided geo-referenced position and community structure of treeline ecotones of the Sagarmatha National Park with special reference to Himalayan fir and Mountain birch in eastern Nepal Himalaya. Spatial and temporal variation in the regeneration patterns of the treeline species is evident from the size class distribution. This study will be a baseline reference to assess and long term monitoring of the impact of the environmental changes including climate change in the treeline vegetation of the Mt. Everest (Sagarmatha) National Park in Nepal Himalaya.

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