Original Article

Effect of altitude and climate in shaping the forest compositions of Singalila National Park in Khangchendzonga Landscape, Eastern Himalaya, India

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ABSTRACT

Himalayas provide high altitudinal gradients and extreme slopes which may rapid changes in climatic zones over a small distance which reflects noticeable changes in the forest community structures. We identified and analyzed various aspects of forest community composition with the effect of climatic variables and altitudes in the Singalila National Park (SNP), Khangchendzonga Landscape in Eastern Himalayas (India). We encountered 2075 woody individuals of 70 species within a transect (2000 m–3636 m asl). The entire forest regime reflected a dominance of young trees and the species richness showed a negative correlation with the altitude. Climatic variables (actual evapotranspiration, potential evapotranspiration and moisture index) are the measures of available environmental energies which drive the final shape of forest community structure. Our study revealed that these forces showed a significant relationship with species richness and altitude of the forest which provides the present shape of forest community composition structure of the SNP.

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Introduction

The recurrent variations in the altitude as well as vegetation type even along a small geographical expanse make Himalayan mountains suitable sites to explore (Korner 2000). The wide altitudinal variations (300–8000 m asl) in many biogeographical realms and climatic conditions (tropical hot to arctic cold) are the driving forces for high variations in vegetation types. The quest to understand the pattern of vegetation composition, its diversification, pattern of change, and the forces behind its diversification along the altitude as well as in different zones has always added the fuel to the intensive field researches all over the world. Many regions of Himalaya are undersurveyed or unsurveyed because of

their tough topography and harsh climate condition; however, the works of Darwin, Wallace, and Von Humboldt are the primary initiatives taken to analyze the change of natural world along elevation (Lomolino 2001). The study patterns in the Himalayan region in recent years are getting deeper into finding the relation of variation of the vegetation structure to various spatial and environmental gradients (Acharya et al 2011; Gaire et al 2014). The species composition and richness depend directly on the altitudinal factors like temperature and air pressure and the factors independent to altitudinal variations such as precipitation and cloud cover (Kromer et al 2013). The species richness has been described to be the effect of these environmental factors in combination or alone (Rosenzweig 1995; Lieberman et al 1996; Whittaker et al 2001; Sánchez-González and López-Mata 2005). The latitudinal and the altitudinal gradients and their effects in the pattern of species composition and community structure of the region have now been the basic and the important steps in any vegetation study in Himalayan context and thereby in understanding the vegetation diversity pattern (Rahbek 1995, 2005; Grytnes and Mc.Cain 2007; Acharya et al 2011; Gaire et al 2014; Bhattarai and Vetaas 2003)

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and in molding the conservation stratagem (Vetaas and Gerytnes 2002; Gaire et al 2014). The population decline range shift and extinction risk of the species can be compared with elevational gradient of the species (Parmesan 2006). Such relationship of species richness to elevation has been linked to the random elevation association between the extent and the position of elevation ranges of species along the geographical extents (Colwell and Hurtt 1994). To explain this relationship, numerous hypotheses have been proposed (Brown and Lomolino 1998; Brown 2001; Lomolino 2001; McCain and Grytnes 2010) in which the area (MacArthur 1972; Rahbek 1997), climate (Odland and Birks 1999), and mass effect (Shmida and Wilson 1985) are widely discussed.

Elevational variation is an umbrella term for numerous climatic and physical variables that changes along with it, directly influences shaping the community composition and structure of the forest, along with the other factors such as anthropogenic activities, historical effects, species area effects, isolation, so on (Rahbek 2005). The studies on the change in vegetation pattern if related to the environmental factors would render more clues in understanding altitudinal effects on vegetation and related climate change scenario (Korner 2000, 2007). Many studies have highlighted the pattern of change in species richness along the elevation gradient, interacting with temperature and moisture, thereby depicting climatic gradient driven scenario (Gentry 1988; O'Brien 1993; Lomolino 2001; Bhattarai and Vetaas 2003; Hawkins et al 2003; Acharya et al 2011). The floristic diversity pattern in Central Himalaya and Western Himalaya as an effect of the altitudinal gradient and in relation to the climatic variables has been studied (Vetaas and Grytnes 2002; Oommen and Shanker 2005; Bhattarai and Vetaas 2006). The Eastern Himalayan forests are among, floristically, the most diverse regions with high endemism (Hajra et al 1996; Behera et al 2002; Rafiqpoor et al 2005). The Eastern Himalayan Mountains represent one of the global hot spots of biodiversity (Mittermeier et al 1999); tree diversity has been analyzed along the elevational gradient covering 2000 m altitudinal amplitude in Eastern Himalaya (Behera and Kushwaha 2007). The Singalila National Park (SNP) in the Eastern Himalaya serves as an ideal site for such vegetation assessments along elevation gradient; there is hardly any earlier work available on the same. Nevertheless, present study expects adding up the knowledge on woody vegetation particularly in relation to altitudinal gradients and climatic variables, as strong first-time baseline data for SNP. Our objectives were (i) to identify and analyze forest communities for their woody species richness, dominance, basal cover, regeneration pattern and along with factors affecting the forest structure such as altitudinal gradient and climate variables and (ii) weighing up the effect of geometric constrains and environmental factors, giving shape to the present structure of the community in SNP.

Materials and methods

Study area

Established in the year 1992, the SNP covers a spatial area of 79 sq. km, extending between 27°13′ 15″ N to 22°1′46″ N latitude and 83°1′91″ to 38°7′54″E longitude, along 2000 m to 3636 m asl. Situated in the extreme north-western boundary of Darjeeling district (West Bengal, India) and along the transboundary location with Nepal and the state of Sikkim, the SNP is one of the 16 notified protected areas in Khangchendzonga Landscape, India, Eastern Himalaya (Badola et al 2016). Frequent and heavy snowfall occurs above 3300 m asl during winters. Sandakphu and Phalut are the two main high altitude destinations for the trekkers. Sandakphu (3636 m asl) is the highest point where from four of the five highest

mountain peaks of the world—Mt Everest, Makalu, Khangchendzonga, and Lhotse can be directly sighted. Also, many other snow-clad peaks of Sikkim, Nepal, Tibet, and Bhutan could be visible in a panoramic view. Phalut summit, a tri-junction of Sikkim, Nepal, and West Bengal, provides a spectacular view of the snow-capped Khangchendzonga peak, located just 48 km apart from this point. The altitudinal gradient, climate, rainfall, and the rivers crossing the region provide diversified microhabitats harboring rich biodiversity. Some of the globally sensitive faunal species found in SNP are red panda (Ailurus fulgens), Himalayan black bear (Ursus thibetanus), and a spectacular diversity of Rhododendron spp., along with many threatened medicinal plant species (Aconitum ferox, Paris polyphylla, Panax sp, and Dactylorhiza hatagirea). Two mighty rivers, one at the eastern side of the Singalila Range, the Teesta River and other the Tamur River to the west (Nepal) and other adjoining tributaries nourish the landscape.

Sampling design

We conducted vegetation study along upper Gorkhey to Phalut. Vertical transects were studied from 2400 m asl (above fringe of Gorkhey village) to 3600 m asl (upto Phalut summit; Figure 1) covering a walking distance of approximately 17 km forest stretch with 1200 m altitudinal amplitude. As the forest village, Gorkhey, falls in the lower part of national park and occupies the large habited area below 2400 m asl, we started the assessment from 2400 m asl upward where forests are devoid of any anthropogenic activities. We followed the stratified random sampling method and identified 10 major sites along the transect based on homogeneity of forest composition and altitude. In each site, 10 random quadrates (10 m × 10 m) were studied, covering approximately 50 × 120 m area/site. We adopted nested quadrate method for the study of trees, shrubs, saplings, and seedlings. We recorded the adult trees within 10 m × 10 m and selected 5 m × 5 m in the center of the same for the shrubs and the tree sapling. For the counting tree seedlings, we laid two 1 m × 1 m quadrates within alternative corners of 5 × 5 m quadrates. At each major site, we counted the number of trees, shrubs, saplings, and seedlings. We measured and considered adult trees having the girth size ≥31 cm (circumference breast height, 1.3 cm above ground level), saplings with a circumference between ≥5 cm and ≤30 cm at 1 cm above ground level and the seedlings with circumference <5 cm at 1 cm above the ground level. We measured the height of the individuals using an altimeter and the circumference using a measuring tape and a digital vernier caliper (Model no.: CD-8″CS, Mituyoto, Japan) as per the case.

Data analysis

We quantitatively analyzed the procured data of woody vegetation for density, relative density, frequency, relative frequency, and relative dominance (Misra 1968) and calculated the important value index (IVI: relative density + relative frequency + relative dominance). We also calculated the values for Margalef's Index of species richness, Simpson's Index of Dominance (Simpson 1949), Shannon—Weiner Diversity Index and Shannon Index of species evenness (Shannon and Wiener 1963).

Climate data

Owing to tough topography of the mountainous landscape and lack of weather stations in the study area, the climate data for the exact targeted site along the altitudinal gradients were not available, therefore, we downloaded the necessary climate data for the
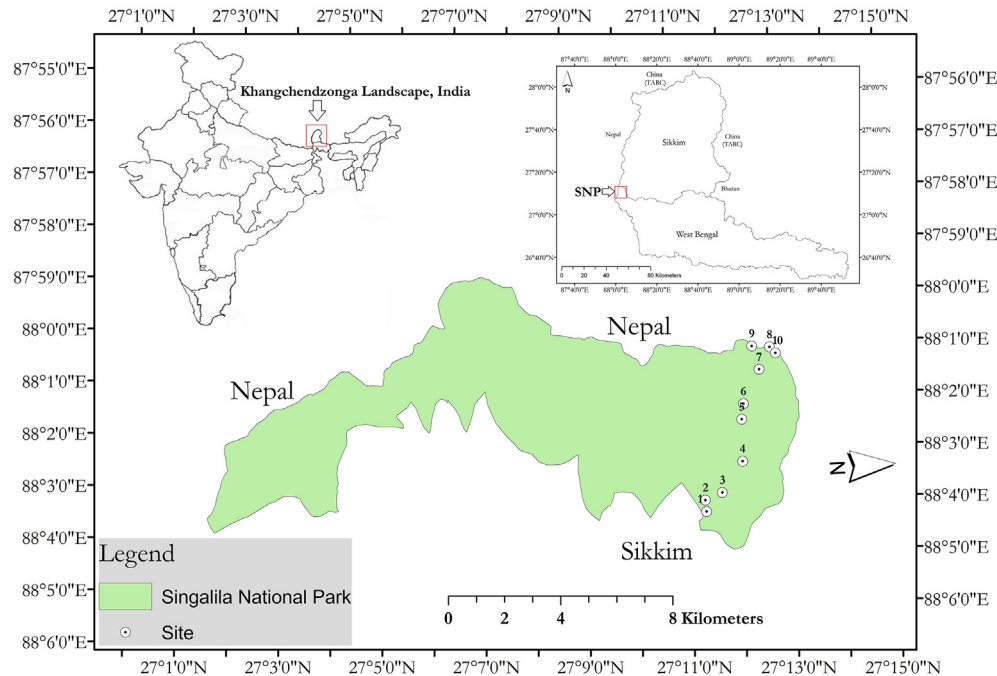
Figure 1. Map of the study area in Singalila National Park in India.

study area from Global Weather data for SWAT (https://globalweather.tamu.edu/) as CFSR data (Climate Forecast System Reanalysis), as followed by Fuka et al 2014 and Dile et al 2016. Depending upon the availability and accessibility, we procured crucial climate data like maximum and minimum temperature, precipitation, and humidity of the selected nine sites at different altitudes (108 m, 121 m, 144 m, 299 m, 653 m, 1272 m, 1779 m, 3170 m, and 3366 m asl.) for the year 2013. Based on these data, we estimated the maximum temperature, the minimum temperature, the precipitation, and the relative humidity of all the 10 study sites of the transect by using regression equations: maximum temperature $= -0.004$ (elevation) $+ 28.94$ ($p < 0.001$), minimum temperature $= -0.002$ (elevation) $+ 17.44$ ($p < 0.02$), precipitation $= -0.001$ (elevation) $+ 9.359$ ($p < 0.04$) and relative humidity $= -2E-05$ (elevation) $+ 0.520$ ($p < 0.1$). From these climate data, we quantified the factors affecting the forest composition and structure, such as potential evapotranspiration (PET) (Bhattarai et al 2004), actual evapotranspiration (AET) (Turc 1954), and moisture index (MI) (Bhattarai et al 2004) for all the studied sites. We quantified these values using the following formulae:

$$\left(\text{PET} = \text{Mean annual Bio Temperature}, \text{i.e. temperature} > 0°C \times 58.93; \text{MI} = \text{PET/Mean annual } \textit{Precipitation}; \right.$$

$$\left. \text{AET} = P \Big/ \left[0.9 + (P/L)^2 \right]^{1/2} \text{ with L } = 300 + 25T + 0.05T^3 \right)$$

Statistical analysis

We used the statistical parameters such as Pearson correlation, AET, PET, MI, estimators (Jackknife1, Chao2), and species–abundance distribution model to better understand the dynamism of the forest communities' composition in the transect.

Results

Forest community structure

Based on IVI, we observed three major vegetation types, viz. temperate broad-leaved forest, temperate coniferous broad-leaved forest, and subalpine vegetation in the study transect. In each study site, IVI analysis helped determining the dominant species (Table 1) as well as the forest types. The *Quercus lineata, Quercus thomsoniana, Quercus lamellosa* were the dominant species in the lower belt (2400 m to 2800 m asl) along with the species of *Symplocos, Eurya,* and *Rhododendron*. The *Rhododendron arboreum* in association with *Vitex heterophylla* dominated the site at 3000 m to 3100 m asl. Between 3200 m asl and 3400 m asl, the area comprises of a mix of Rhododendrons in consociation with silver fir. Above 3400 m asl, the conifers declined and *Quercus* spp., *Symplocos* spp., and *Litsea* sp. dominated the scene. Above 3500 m asl the scrubs of *Rhododendron lepidotum* and shrubberies of *Gaultheria* spp. dominated the subalpine vegetation. Although the dominance of conifers started from 3200 m asl, the *Abies densa* and *Tsuga dumosa* appeared from 2600 m asl (Table 1).

Floristic

The vegetation of the region has extended vertically in three successive layers. The average height of the upper storey of the communities, with the cover of dominant tree species, stretched from 9 m to 18 m. Next was the layer of tree saplings and shrubs;

Table 1. Details of major study sites, their dominant species with associated species, and the forest types in Singalila National Park.

Transect site	Elevation (m asl)	Latitude	Longitude	Dominant vegetation	Forest type
Site 1	2400	27°11.3643′	88°04.127′	*Quercus lineata, Rhododendron arboreum, Symplocos theifolia*	Temperate broad-leaved forest
Site 2	2600	27°11.352′	88°03.908′	*Eurya acuminata, Symplocos theifolia, Quercus thomsoniana*	Temperate broad-leaved forest
Site 3	2800	27°11.691′	088°03.824′	*Quercus lamellosa, Rhododendron arboreum*	Temperate broad leaved forest
Site 4	3000	27°12.108′	088°03.157′	*Rhododendron arboreum, Vitex heterophylla*	Temperate broad-leaved forest
Site 5	3100	27°12.577′	088°02.372′	*Rhododendron arboreum, Vitex heterophylla*	Temperate broad-leaved forest
Site 6	3200	27°12.187′	088°02.096′	*Rhododendron arboretum, Abies densa*	Temperate coniferous broad-leaved forest
Site 7	3300	27°12.192′	088°02.04′	*Rhododendron falconeri, Abies densa*	Temperate coniferous broad-leaved forest
Site 8	3400	27°12.514′	088°1.451′	*Rhododendron barbatum, Symplocos theifolia*	Temperate coniferous broad-leaved forest
Site 9	3500	27°12.577′	088°1.098′	*Gaultheria pyroloides, Gaultheria trichophylla, Rhododendron lepidotum*	Subalpine
Site 10	3600	27°12.701′	088°0.873′	*Berberis aristata, Rhododendron lepidotum*	Subalpine

the middle storey was mainly up to 2 m height on the sites dominated by *Yushania maling* and in other places from 0.5–1.5 m with various shrubs species like Gaultheria, *Berberis, Cotoneaster, Rosa*, and mixed with scattered shrubs like *Daphne, Rubus, Aconogonum, Cardamine, and Osbeckia*. The dense growth of *Y. maling* reaching upto 3400 m asl made it an important floristic group of the region. *Berberis* species spreads throughout the transect with the greater density along 3100 m to 3600 m asl. The other less predominant shrubs were *Rosa* sp., *Gaultheria* sp., and *Aconogonum molle*. The ground layer was represented by herbaceous flora; there were appreciable amount of moss, lichens, mushrooms, and ferns. Table 2 provides the relative density and relative frequency of the selected shrubs in each site. We recorded marked presence of *Berberis aristata, Gaultheria pyroloides, Gaultheria trichophylla*, and *Rosa* sp. above 3300 m asl, reflected by their high relative density and high relative frequency. However, we observed frequent presence of *B. aristata* in many sites with a relatively high frequency. In the higher ranges beyond 3400 m asl, Iris decora along with the scrubs of *Rhododendron* spp., forms the common vegetation composition.

Elevation pattern of distribution of woody taxa

In all the study sites, within all quadrates, we counted a total of 2075 woody individuals belonging to 70 species. Above the 3400 m asl, we did not observe any tree; the *R. lepidotum* (scrub) and other stout shrubberies dominated the subalpine region in association with large patches of alpine meadows. The Figure 2 shows the density of tree species and shrubs along the altitude. The trees (adults and saplings) were negatively correlated (r = −0.697) and shrubs were positively correlated (r = 0.626) with the altitude at

$p < 0.05$ level. We recorded the maximum number of woody individuals at 3500 m asl (44160 individuals/ha) and minimum at 2800 m asl (5027 individuals/ha). Of 70 identified woody species, none occurred throughout the altitudinal zone. Overall, we recorded the highest tree density at 3300 m asl (8128 individuals/ha) and lowest at 3400 m asl (2279 individuals/ha). Sapling density gradually declined from 2400 m asl (3552 individuals/ha) to 3000 m asl (300 individuals/ha) and was not uniform after 3100 m to 3400 m asl. We recorded the highest seedling density (2633 individuals/ha) at 3300 m asl and lowest at 3400 m asl (200 individuals/ha). Regeneration pattern (sapling and seedling density combined) gradually declined from 2400 m to 3000 m asl after which it increased steadily upto 3300 m asl. At 2400 m, 2600 m, and 3400 m asl, we observed higher number of saplings than the mature individuals (Figure 2). *Eurya acuminata, T. dumosa, Rhododendron grande*, and *Rhododendron barbatum* showed maximum altitudinal amplitude (2400 m to 3400 m asl), and species like *Machilus, Thuja*, and *Acer campbellii* were found at single site only. Among the dominant trees of each study site, *Rhododendron* spp. showed the highest regeneration at 3400 m asl, followed by *Symplocos* spp. and *Illex* spp. At 3200 m asl, we recorded the seedlings of maximum number of species (10 species), and the site is suggested for the promotion of conservation practices for future. We quantified the regeneration pattern of trees for the eight sites upto 3400 m asl, since the two remaining sites (3500 m and 3600 m asl) were devoid of trees.

Regeneration pattern of woody species

Based on Diameter at breast height (DBH) class distribution of the total tress in the study area (C = 10–20 cm, D = 20–30 cm, E = 30–40 cm, F = 40–50 cm, G = 50–60 cm, H = 60-70 cm, I = 70–80 cm, J = 80–90 cm, K = 90–100 cm, and L > 100 cm), we quantified the regeneration pattern of woody species. As per the 10 classes of DBH, the maximum "C" class of DBH was observed followed by D, E, F, G, H, I, J, K, and L. This suggests the forests have good regeneration pattern with more young individuals than the matured ones (Figure 3).
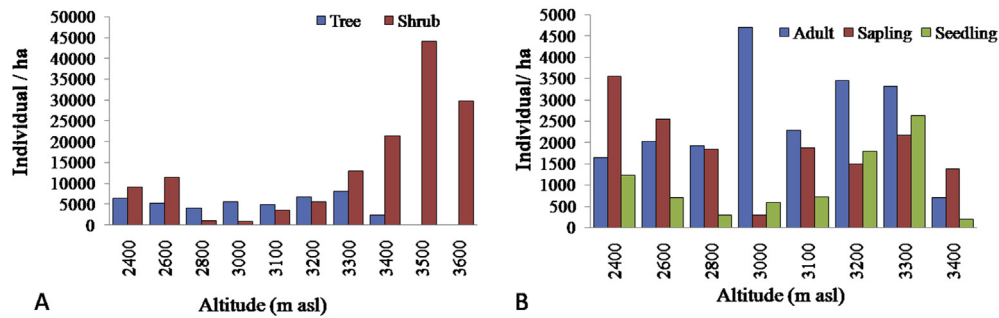
Ecological indices

The regression line drawn between the species richness and elevation gradient showed a significant quadratic relationship ($R^2 = 0.734$, $p < 0.002$), as the species richness decreased with increasing altitudinal gradient (Figure 4). Whereas, the Simpsom's Index of Dominance and the altitude demonstrates a positive quadrate relation ($R^2 = 0.436$, $p < 0.077$; Figure 4). We quantified a declining trend among the Shannon−Weiner Diversity Index ($R^2 = 0.524$, $p < 0.018$; Figure 4) and the Shannon Index of species evenness ($R^2 = 0.311$, $p < 0.096$; Figure 4) with the increasing altitudinal gradient in the forests.
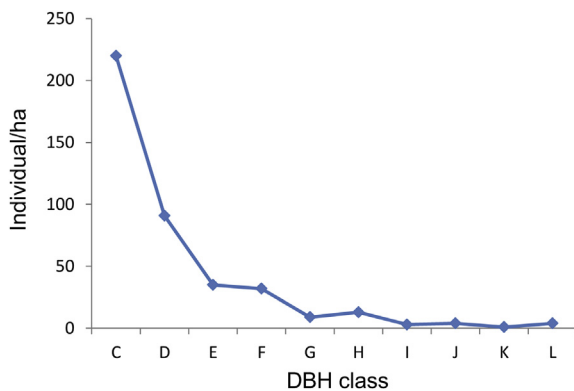
Table 2. Important associated shrubs of each study site, with their higher relative frequency, and relative density in Singalila National Park.

Site	Important shrub species	Relative density	Relative frequency	A/F ratio
1.	*Aconogonum molle*	1.53	8	0.23
	Rubus lineatus	1.53	8	0.23
	Cardamine macrophylla	2.71	8	0.4
2.	*Aconogonum molle*	4.74	4.35	9.09
	Cirsium verutum	2.09	8.7	10.79
3	*Berberis aristata*	0.25	14.29	2.5
	Daphne cannabina	0.25	14.29	0.05
4.	*Berberis asiatica*	0.19	13.33	0.05
	Actinidia callosa	0.19	13.33	0.05
5.	*Berberis aristata*	5.12	16.67	0.5
6.	*Berberis aristata*	8.66	15.38	0.05
	Gaultheria trichophylla	3.46	7.69	0.08
7.	*Rosa* sp.	31.9	10	5.2
	Daphne cannabina	14.72	10	2.4
8.	*Gaultheria trichophylla*	58.82	18.18	2.25
9.	*Gaultheria pyroloides*	61.59	23.08	1.89
	Gaultheria trichophylla	25.36	23.08	0.78
10.	*Berberis aristata*	67.03	50	0.78

Figure 2. A, Distribution of woody species along the elevation gradient in Singalila National Park; B, observed density of adult trees, saplings, and seedlings along the altitudinal gradient in Singalila National Park.
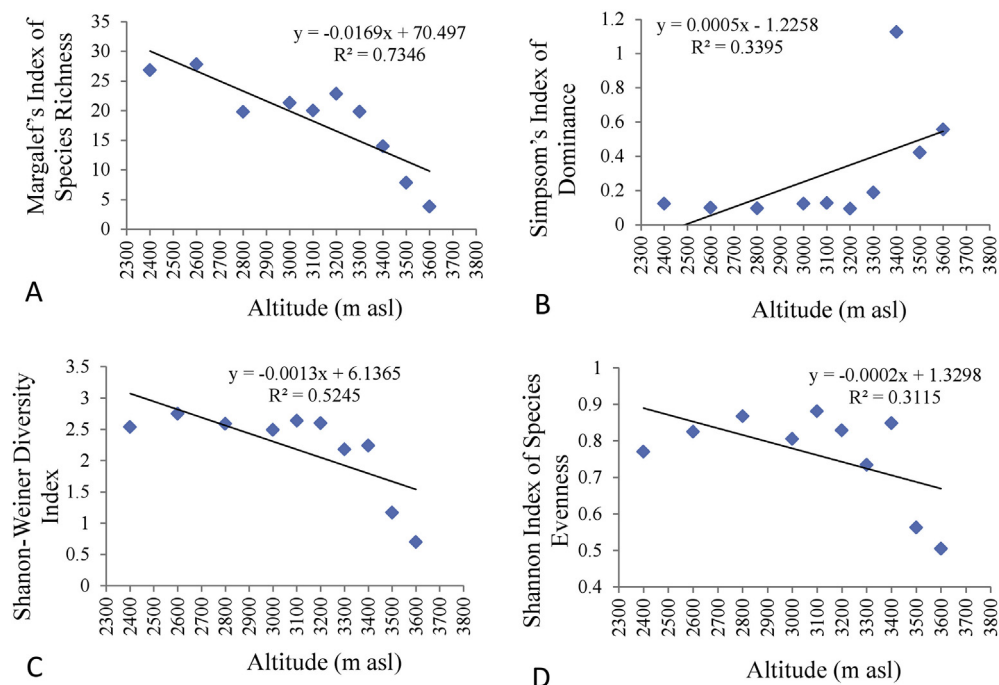

Figure 3. Estimation of DBH class distribution of the total trees in Singalila National Park. C = 10–20, D = 20–30, E = 30–40, F = 40–50, G = 50–60, H = 60–70, I = 70–80, J = 80–90, K = 90–100, L > 100.

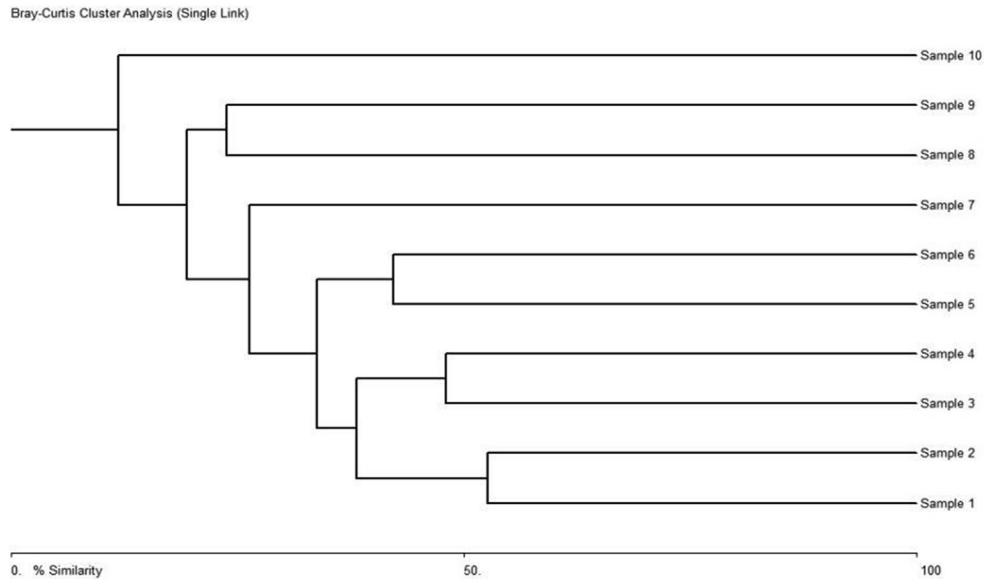### Cluster analysis for the forest structure and composition

The cluster analysis among the samples of the 10 different sites provided us the picture of their forest composition structure as well as similarity and dissimilarity level along the altitudinal gradient (Figure 5). The cluster analysis revealed that the site 1 and 2 had the maximum species composition similarity (>50%) among all sites. Overall, the sites showed a similar trend of species composition similarity distribution of species; however, the site 7 and 10 indicated maximum dissimilarity with their neighbor sites, and the trends of distribution of the species composition similarity decreased with increasing altitudinal gradient of the transect.

Estimator Jackknife1 and Chao2

We quantified species estimators, namely Jackknife1 and Chao2, and correlated these with the altitudinal gradient of the study area. We recorded total 70 woody plant species in the study transect, however the Jackknife1 (96 species) and Chao2 (77 species) were

Figure 4. A, Observed Species richness along the elevation gradient in Singalila National Park; B, observed dominance along the elevation gradient in Singalila National Park; C, observed diversity along the elevation gradient in Singalila National Park; D, observed species evenness along the elevation gradient in Singalila National Park.

Figure 5. Cluster analysis showing the similarity group among the study sites in accordance to the floristic composition and richness in Singalila National Park.

estimated for higher number of species. Similarly, we drew the regression line between species estimators and the altitudinal gradient and quantified the significant negative quadratic relations, Jackknife1 ($R^2 = 0.734$, $p < 0.01$) and Chao2 ($R^2 = 0.797$, $p < 0.01$) (Figure 6). Likewise, we observed a declining trend of Jackknife1 and Chao2 with increasing altitudinal gradient in the forest. As per Jackknife1 and Chao2 estimator, there may be more possibilities to find new species in the forest.

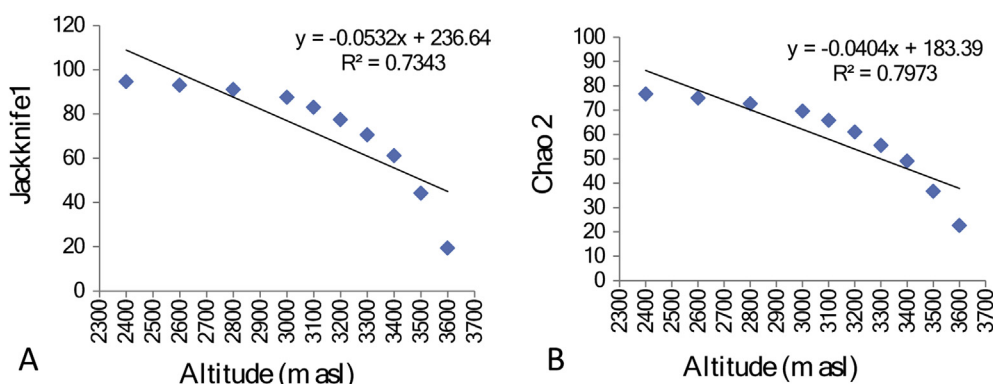*Species-abundance distribution pattern*

We used four models to describe the species–abundance distribution pattern of ecological community such as geometric, log series, truncated log-normal, and MacArthur's broken stick (Magurran and McGill 2011). Among four models for vegetation data of the present study, the log series of normal distribution pattern appeared best fitted and that showed no significant difference of observed and expected number of species in each abundance class ($\chi^2 = 1.72899$; $p = 0.785446$; df = 4). In the log series model, we observed the species-abundance distribution as a histogram and the expected species-abundance distribution as a line. The species-abundance distribution pattern showed that few species were rare in the forest community (Figure 7).

Relationship between climate variables and altitudinal gradient

We estimated and quantified climatic variables, such as mean annual maximum temperature, mean annual minimum temperature, mean annual precipitation, and mean annual relative humidity of the 10 sites along altitudinal gradient from in or around stations data of the study area. We also observed that all climatic variables declined with increasing altitudinal gradient of the study area (Figure 8).

Relationship among climate variables (PET, AET, and MI), species richness, and altitudinal gradient

From the four climate variables, we also quantified PET, AET, and MI of the study area and correlated them with species richness of the forest to better understand the factor affecting composition and structure of the forest communities. The result indicates that AET, PET, and MI are the measures of available environmental energies which have driven the final shape of community composition and structure of the forest. The study revealed that these forces have a significant positive correlation with the species richness and a negative correlation with the altitudinal gradient (Table 3).

Figure 6. Estimated species richness of the woody taxa along in Singalila National Park: A, Jackknife1; B, Chao2
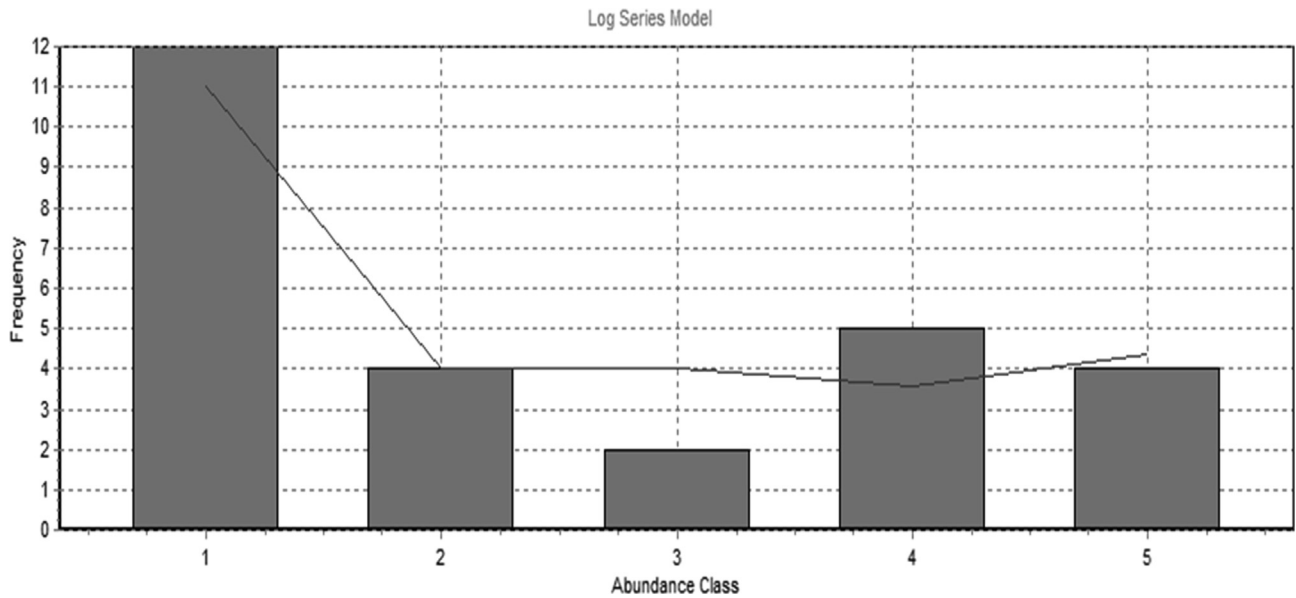
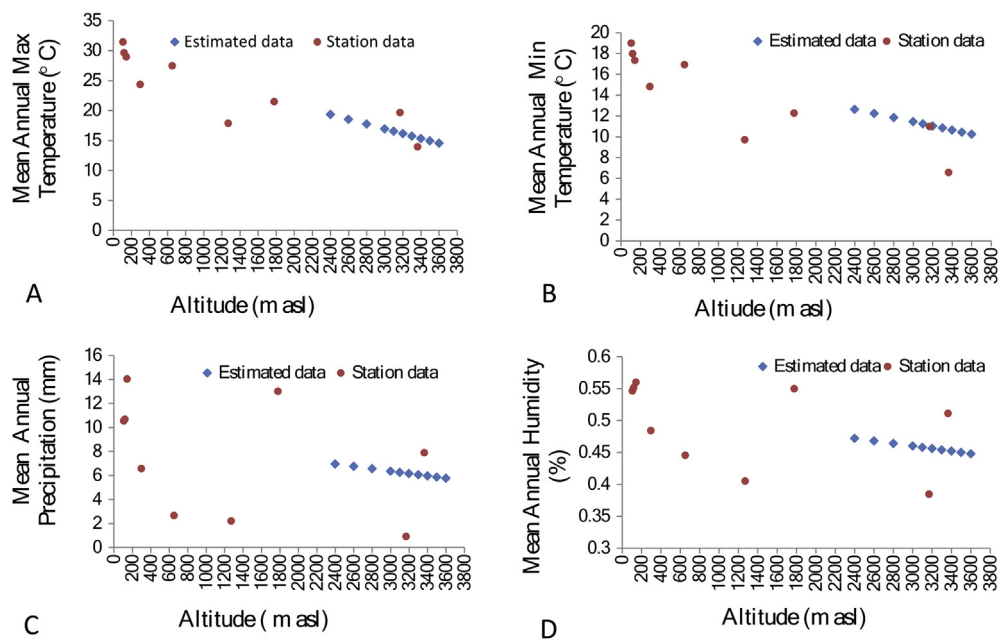**Figure 7.** Log series model of normal distribution pattern of woody taxa in Singalila National Park.

Figure 8. Relationship between elevation and climate variables in Singalila National Park: A, mean annual maximum temperature; B, mean annual minimum temperature; C, mean annual precipitation; D, mean annual relative humidity.

Discussion

Mountain slopes with significant bioclimatic amplitude generally have more species at the bottom than the top (Vetaas and Grytnes 2002). In our study in SNP in Khangchendzonga Landscape, having transboundary location with Nepal, the woody species richness

Table 3. Pearson correlation of species richness versus. climatic variables for Singalila National Park.

Species richness		Temperature	MI	AET	PET
Pearson Correlation	r	0.856	0.875	0.856	0.856
	p	0.01	0.01	0.01	0.01

AET = actual evapotranspiration; MI = moisture index; PET = potential evapotranspiration.

along altitudinal gradient showed a uniform decline with decreasing bioclimatic variables like temperature, MI, PET, and AET and inversely with altitudinal gradient. The studied transect starts from temperate forest to subalpine forest covering amplitude of 1200 m. The region experiences high fluctuation of climate leading to change in species richness and diversity along the altitude. Based on IVI analysis, we recorded three different forest types, cold temperate broad-leaved forest, cold temperate coniferous broad-leaved forest, and subalpine forest. The dominant vegetation type changes along the altitudes, where the species like *Quercus, Rhododendron, Symplocos, and Abies* were dominant, when assessed for the whole area including the quadrates' sites. Apart from the tree species, the study area also harbors varieties of shrub species, in combination with which the total number of woody species increases from lower

elevation to the higher elevation. The tree density, as determined by its regeneration potential under the influence of the prevailing environmental factors in the region (Tripathi et al 2004; Sagar et al 2008), appeared to be greater at 3,300 m asl and lowest at 3,400 m asl. At 3300 m asl, the relative density of *Rhododendron* spp., 57.73 of adult tree, 46.46 of the saplings, and 39.47 of the seedlings, appeared relatively higher compared to other associated species. The 100 m rise in the altitude showed no support to the growth of the trees and thus the overall density of the adult trees, saplings, and seedling decreased. We noted that the climatic variables prevailing at 3300 m asl are favorable for the growth of tree species especially the Rhododendrons. The species shifting toward the higher elevation, coping up with the changing climate, can be a factor for the accumulation of higher number of individuals in this range, beyond which the survival of some of the species is less supported. The overall increase in the density of one or two common species compensates the reduction in the number of rare species at higher elevation thereby increasing overall density (Scott 1976). High plant density at higher elevations might appear as an adaptation to withstand the cold climatic condition and strong wind (Acharya et al 2011), thus opting for an alpine refugia (Gentili et al 2015). Among the dominant species, the regeneration rate of *Rhododendron* is seen to be good with relatively more number of saplings and seedlings along the entire transect followed by species of *Symplocos*. The tree density in temperate mixed coniferous broad-leaved forest belt (above 3200 m to 3400 m asl) came out significantly higher than in the lower belt. We observed highest species diversity along 2400 m to 2600 m asl. This may be because of the presence of slightly warmer temperature associated species in the sites having limited tolerance toward colder region beyond which the climatic variables act upon their survival chances, and hence these species are localized only to specific habitats (Jetz and Rahbek 2002). The factors like habitat availability, dispersal and establishment abilities, competition, local abundance, or other climatic variables allocate the distribution of species in the vegetation (Gaston 1996). According to DBH classes, the number of young individuals of adult are maximum having 10—20 cm range and follows a gradual inverse proportion. This shows the presence of higher density of young trees of the overall species, which signifies a healthy growing forest, provided the appropriate forest conservation management practices applied. In SNP, the basal area marks its peaks at the mid elevation (3000 m asl), which is because of the presence of greater number of adult tree species (Rhododendrons) compared to the other sites. The relatively lower basal cover of the trees at 3400 m and 3300 m asl may be the result of the greater young woody plant density to be the effect of cold and harsh climatic conditions (Acharya et al 2011). We observed a total 70 species in the transect and according to nonparametric species richness estimators, Jackknife1 (96) and Chao2 (77) showed slightly greater number of species richness in the forest, as a result there might be some possibilities of getting newer species in the transect. However, the observed species richness pattern also followed a similar trend to the estimated ones as calculated by Chao2 and Jackknife1. Based on the species-abundance distribution pattern, we used four models; geometric, log series, truncated log-normal, and MacArthur's broken stick (Magurran and McGill 2011). Among them, the forest community composition was best fitted under the log series model. The log series model of species-abundance distribution suggested the presence of few rare species in the study transect. The structure and community compositions of the forests at high altitude are controlled by both environmental and biological factors (Komarkova and Webber 1978; Chaurasia and Singh 1996; Kala 2000); we observed a strong relationship between the climatic variables and the species richness along with altitudinal gradient of the forest. Also, the energy and water plays a significant role in plants' overall physiological processes and ultimate survival, thus in shaping their distribution and community composition along with species richness of forests (O'Brien 1993; Hawkins et al 2003). Furthermore, climate dependent water—energy variables affect the species richness of the forest, as explained by Carpenter from Central Himalayan elevation gradient (Bhattarai et al 2004; Archarya et al 2011). Similarly, in our study area, the gradual upward decline in the species richness may be a consequence of the decreasing humidity, precipitation, and temperature along the altitudinal gradient. The factors affecting the structure and community composition of forests such as AET, PET (Currie 1991), and MI are the driver forces which control the species richness of the forest along with better shaping the forest. Furthermore, we encountered relatively more species at 3100 m and 3200 m asl in the transect, which may be due to shifting of lower belt species toward an altitudinal gradient in the transect or may be that the region is slowly molding into ecotone zone. Therefore, along with the anthropogenic and historical factors, the structure and community composition of the forest cover in SNP is directly and indirectly dependent upon climate variables along with altitudinal gradients.

Conclusion

Our study helps to weigh up the geometric constrains and the effect of environmental forces and in giving shape to the present structure and community composition of the forest in Eastern Himalayan region (SNP). The spatial and temporal distribution of the species of any forest is not only the effect of the topography and anthropogenic activities but is equally under the influence of climatic forces. Our result highlights the relationship between the species richness and climatic variables; wherein, the climatic variables taken into account for the site affects the species richness pattern, which declined in accordance to the decreasing temperature, humidity, and precipitation along the altitudinal gradient of the study area. The adaptability of species in different climatic conditions and in different community composition can be analyzed further. Thus, the changing climate in the Himalayas will profusely effect in the species composition, survival, and spread of the species along the range, and any future conservation stratagem needs to be developed taking this important prospective of climatic variables into account.

Conflicts of interest

The authors declare that there is no conflicts of interest.

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