10 Vegetation Structure Along an Elevation Gradient at the Treeline Ecotone of Eastern Himalayan Forests in Sikkim

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Abstract

This chapter presents an extensive vegetation analysis for Yuksam-Dzongri transect in Sikkim (in the eastern Himalaya). The investigation was conducted along an elevation gradient between 1700 m and 4000 m at 100 m elevation steps and considered its physiognomy life form, species-area relationships and species compositional changes. The plant species assemblages in the transect was represented by 267 species belonging to 174 genera and 81 families. The familial composition showed the predominance of Ericaceae, Fagaceae, and Lauraceae in tree layer; Ericaceae, Rosaceae, Berberidaceae, and Rubiaceae in shrub layer, and Compositae, Polygonaceae, Rosaceae, and Primulaceae in the herb layer. The species richness (tree, shrub, and herb) and total basal area (TBA) of trees declined monotonically along the elevation gradient with peaks at 1700–1900 m. The tree density in present studied transect was significantly higher than in its western Himalayan counter parts of Indian Himalayan region. The presence of 77 tree species in the high forested zone highlights the high tree species richness of the eastern Himalaya to which the contribution of *Rhododendron* was particularly high. Sparse canopy layer and dense undercanopy tree layer were the characteristic features of the forests. Further, inclusion of biotic interactions and disturbance may improve ecological understanding of these patterns of plant species richness across the Indian Himalayan region.

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Keywords

Eastern Himalaya · Elevation gradient · Sikkim · Species richness · Treeline

10.1 Introduction

Variability in environmental factors along the elevation gradient plays an important role in shaping the distribution patterns of plant species in mountainous landscapes (Hunter and Yonzon 1993; Vetaas and Grytnes 2002; Baniya et al. 2012; Rai et al. 2018). An elevation transect in the Himalaya supports diverse vegetation types from tropical monsoon forest to moist alpine scrub and meadows (Singh and Singh 1992). Diversity and distribution of species are influenced by their physiological tolerance and competitive ability in environmental variables, such as elevation, exposure to radiation, moisture, precipitation, substrate attributes, temperature, and topography (John and Dale 1990; Belnap and Gillette 1998; Ponzetti and McCune 2001). Therefore, elevation gradients are particularly suitable for detecting climate change and assessing climate change impacts (Nogués-Bravo et al. 2008).

Although many theoretical explanations are available, still patterns of plant species distribution along the elevation gradient are debatable (Sharma et al. 2019). Several postulations about species richness patterns along the elevation gradients have been proposed. Among them, monotonous decline in species richness with elevation gain (Odland and Birks 1999; Körner 2004; Saikia et al. 2017; Shooner et al. 2018) and mid elevation peak showing hump-shaped pattern of species richness (Carpenter 2005; Manish et al. 2016) are most prominent. In the Himalaya, the hump-shaped pattern of species richness is most common, (Grytnes and Vetaas 2002; Bhattarai and Vetaas 2006; Acharya et al. 2011; Pandey et al. 2018b). Reports on monotonic decline in tree species richness with elevational gain are also available (Sharma et al. 2009; Bhattarai and Vetaas 2006).

The East Himalayan state, Sikkim offers an ideal research area for studying elevational influence on phytodiversity (Pandey et al. 2018b). Acharya et al. (2011) have analyzed the tree richness pattern involving data points from 23 sample locations at every 100 m interval between 300 and 4700 m. Manish et al. (2016) have studied life forms (herb, shrub, and tree), richness of angiospermic plants using 51 elevational bands of 100 m each along 300–5300 m elevation gradient. Pandey et al. (2018b) have studied changes in vegetation attributes using 11 elevational bands of 100 m each along 3000–4000 m elevation gradient in Khangchendzonga National Park. Sharma et al. (2019) studied richness pattern of life forms (herb, shrub, and tree) in an elevation gradient 500–3300 m using 28 elevation bands of 100 m each. Besides elevation, the ecotone effect in transitional zones is also reported in eastern Himalaya (Oommen and Shanker 2005; Behera and Kushwaha 2007). Further, the eastern Himalaya possesses an ultra-varied topography that fosters species diversity and endemism (Myers 1988). Thus, for better understanding of phytodiversity patterns, there is a need of detailed study focusing on various ecological attributes along elevation gradient. This study focuses on analyzing the patterns of the life-form richness of vascular plants, vegetation structure, species composition, and distribution along an elevation gradient from mixed broad leaved forest to treeline ecotone between 1700 and 4000 m in Sikkim.

10.2 Materials and Methods

10.2.1 Study Area

This study considers a Yuksam-Dzongri transect located in West district of Sikkim state in the Eastern Himalaya (Fig. 10.1). The Yuksam-Dzongri transact covers an elevation gradient of 2400 m starting from mixed broad-leaved forest at 1700 m to moist alpine scrub at 4000 m. Nestled in Khangchendzonga Biosphere Reserve (KBR), the transect runs across the undisturbed forest ridge supporting *Prek Chu-Rathong Chu* Catchment. Most of the area of Yuksam-Dzongri transect falls within the Khangchendzonga National Park (KNP) the first "Mixed World Heritage Site" of

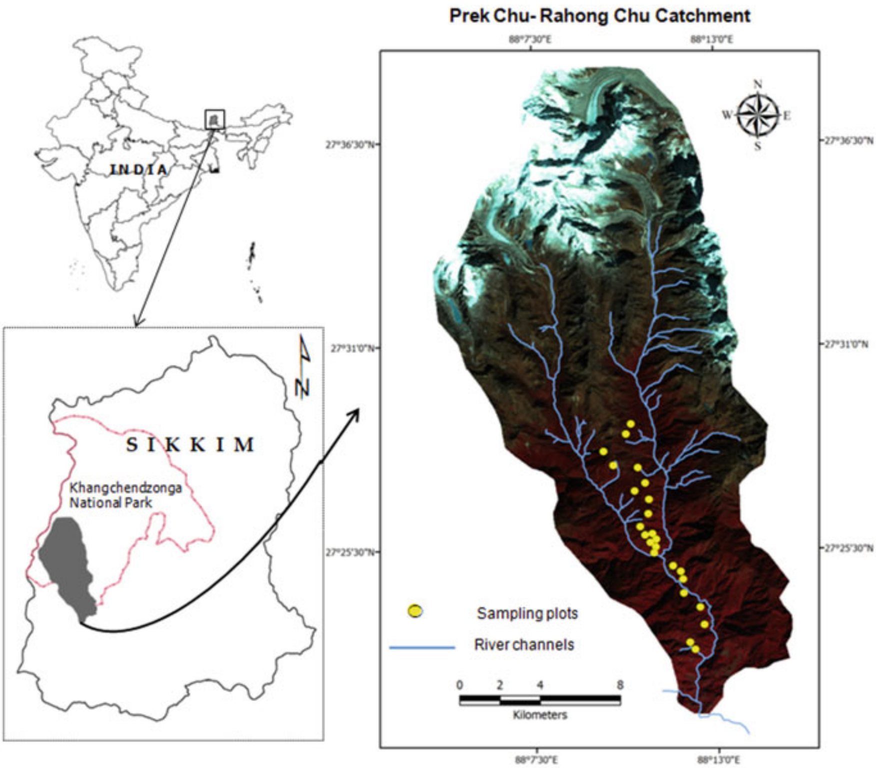

Fig. 10.1 Map showing location of Khangchendzonga National Park (KNP), Sikkim in northeast India and various sampling location distributed over different elevation in Prekchu-Rathongchu Catchment

India on UNESCO World Heritage List under both cultural and natural heritage category (Pandey et al. 2018a, b). The KNP covers an area of 1784 km^2 (approx. 25% of the geographical area of Sikkim state) and located between 27°03′41″ and 28°7′34″ N latitude and, 88°03’40″ and 88°57′19″ E longitude. The area under KNP varies from 1220 m to 8586 m elevation (Mount Khangchendzonga peak) includes a wide range of vegetation with a considerable area under subalpine forests and alpine meadows. The climate is monsoonal with annual precipitation of 1021.0 ± 157.01 mm, and mean annual temperature 5.68 ± 1.79 °C with maximum temperature of warmest month 15.93 ± 1.64 °C and, minimum temperature of coldest month −8.36 ± 3.47 °C (Hijmans et al. 2005; http://www.worldclim.org).

10.2.1.1 Vegetation Sampling and Data Analysis

Three 0.1 ha plots (50 m × 20 m) were sampled in every 100 m elevational the mixed-broad-leaved forest to moist alpine scrub (1700–4000 m). In each 0.1 ha plot, five 10 m × 10 m quadrats were laid randomly for enumerating tree species, and in every 10 m × 10 m quadrats one 5 m × 5 m sub-quadrat was laid randomly for enumerating shrub species, and four 1 m × 1 m random quadrat to sample herb species (Pandey et al. 2018b). All individuals of species present within the quadrats were enumerated. Woody stems of size ≥10 cm girth at breast height (1.37 m from the ground) were measured and the height of each stem was recorded. The voucher specimens of sampled species were put up on herbarium sheet and identified by consulting herbaria and regional flora (Hooker 1872–1897; Maity et al. 2018; Ghosh and Mallick 2014). The accepted plant species names and families were adapted from The Plant List (2013).

The data collected in the field along elevation gradient were analyzed to obtain the values of density, frequency, and total basal area of the species following Misra (1968) and Mueller-Dombois and Ellenberg (1974). A frequency distribution was developed in five frequency classes of Raunkiaer (1934). The importance value index (IVI) was calculated by the summation of relative values of frequency, density, and basal area (Curtis and McIntosh 1950). The Shannon’s diversity index (H') was calculated following Shannon (1948), Simpson’s dominance index was calculated following Simpson (1949) and Pielou’s index of evenness was calculated following Pielou (1975). Species richness was determined as the total number of species in sampled area for different life forms. Linear regression analysis was used to understand the linear/quadratic relationship between tree diversity and tree richness with elevational gradients.

The tree species were classified in to following growth forms: large tree, medium tree, and small tree following Whitehurst et al. (2013) and Kumar (2014). The species which occupied upper canopy and emergent strata (≥15 m) were large species, species which occurred in middle canopy (−15 m) were moderate size species, and the species which were restricted to understory (<5 m) were small trees. For phanerophytic life form, each tree species was classified into following life forms; megaphanerophyte (>25 m), mesophanerophyte (>8–25 m), and microphanerophyte (2–8 m) following Raunkiaer (1934).

10.3 Results

A total of 5959 (≥10 cm) tree individuals were recorded in 3.6 ha area that was sampled along the 1700–4000 m elevation gradient for tree layer. They belonged to 32 families, 48 genera, and 77 species, and were distributed across five forests types. In shrub layers, a total of 7862 individuals belonging to 56 species, 42 genera, and 21 families were recorded, and in herbaceous layer, a total of 35,935 individuals of 134 species belonging to 95 genera and 50 families were recorded. Thus about 50% species were woody, which is close to global scale percentage of woody species (43%).

10.3.1 Forest Type Distribution

The elevation transect was divisible into five forest types based on dominance of trees: (1) mixed-broad leaved forests between 1700 and 2000 m, (2) oak-dominated forests between 2300 and 2700 m, (3) rhododendron mixed forests between 2800 and 3000 m, (4) conifer mixed forests between 3100 and 3900 m, and (5) moist alpine scrub, in and around treeline at 4000 m (Table 10.1).

10.3.2 Family Dominance

In tree layer, out of 32 families, 18 had a single species each, 4 families had two species each, and 6 families had three species each. The most speciose families were Ericaceae (14 species), followed by Fagaceae (7), Lauraceae (7), and Rosaceae (5). At generic level, Lauraceae topped the list with five genera and Fagaceae and Araliaceae followed with three genera each. As many as 21 families had single genus each and 8 families had two genera each (Table 10.2). Of the 21 shrub families, seven families had a single species each, another seven had two species each, and three families had three species each. The most speciose families in shrub layer were Ericaceae (11), Rosaceae (7), Berberidaceae (4), and Rubiaceae (4). At generic level Rosaceae with five genera were most important families, and Ericaceae and Rubiaceae followed with four genera each (Table 10.3). In herbaceous layer, out of 50 families, 25 had a single species each, 6 had two species each, and 10 had three species each. The most speciose families in herb layer were Compositae (17), Polygonaceae (10), Rosaceae (8), and Primulaceae (7). At generic level Compositae were topped with 12 genera, followed by Ranunculaceae with five genera, Polygonaceae and Rosaceae with four genera in each (Table 10.3).

10.3.3 Physiognomy, Life Form, and Frequency Distribution

The tree height was between 25 and 28 m for emergent tree species, between 15 and 25 m for upper-canopy tree species, between 5 and 15 m for middle canopy tree

Table 10.1 Vegetation attributes of sampling plots along the elevation gradient (1700–4000 m) in Yuksam-Dzongri transect, Khangchendzonga National Park (KNP), Sikkim

Elevation (m)	Forest types	Dominant tree species
1700	Mixed-broad leaved forest	*Schima wallichii*, *Macaranga indica*, *Engelhardtia spicata*, *Castanopsis hystrix*, *Castanopsis tribuloides*, *Litsea cubeba*, *Leptobotia elongata, Lyonia ovalifolia*, *Eurya* spp., *Prunus cerasoides*, *Symplocos glomerata.*, *Alnus nepalensis*
1800		
1900		
2000		
2100		
2200		
2300	Oak-dominated forest	*Quercus lamellose*, *Quercus lineata*, *Lithocarpus pachyphyllus*, *Laniisoma elegans*, *Alnus nepalensis*, *Cinnamomum impressinervium*, *Castanopsis hystrix*, *Prunus bracteopadus*
2400		
2500		
2600		
2700		
2800	Rhododendron mixed forest	*Rhododendron arboreum*, *Rhododendron falconeri*, *Rhododendron grande*, *Magnolia hodgsonii*, *Tsuga dumosa*
2900		
3000		
3100	Conifer mixed forest	*Abies densa*, *Tsuga dumosa*, *Rhododendron hodgsonii*, *Viburnum nervosum*, *Sorbus microphylla*
3200		
3300		
3400		
3500		
3600		
3700		
3800		
3900		
4000	Moist alpine scrub	*Rhododendron wigthii*, *Rhododendron lanatum*, *Rhododendron thomsonii*, *Sorbus microphylla*, *Symplocos dryophila*

species and for below 5 m for understory species. The majority of tree species along the elevation gradient were large tree (29), followed by medium (28) and small trees (20) (Table 10.4). The number of individuals of tree species was high for small trees followed by medium and large trees. In term of IVI, large trees shared the higher value followed by small and medium trees (Fig. 10.2). The forests of Sikkim Himalaya exhibited a phanerophytic life form, where mega- and meso-phanerophytes were dominant in number of species, number of individuals, basal area, and importance value index (Fig. 10.3). The proportion of evergreen species was much higher than the proportion of deciduous tree species in all phanerophytic life form.

In Raunkiaer's frequency occupancy, 82.1% of tree species belonged to class "A" with ≤20% frequency of occurrence (Fig. 10.4), 12.3% of species belonged to class

Table 10.2 Familial composition (number of species and genera, and different growth form) of tree layer in different forest types along the elevation gradient in Khangchendzonga National Park, Sikkim. The total number of family was 32

Family	Number of genera	Number of species	LT	MT	ST
Actinidiaceae	1	1	1		
Adoxaceae	1	1			1
Anacardiaceae	1	1		1	
Aquifoliaceae	1	1	1		
Araliaceae	3	3		2	1
Betulaceae	2	3	3		
Cornaceae	1	1		1	
Elaeocarpaceae	1	1	1		
Ericaceae	2	14		5	9
Euphorbiaceae	1	1	1		
Fagaceae	3	7	7		
Garryaceae	1	1		1	
Hamamelidaceae	1	1	1		
Juglandaceae	2	2	2		
Lamiaceae	2	2		2	
Lauraceae	5	7	2	5	
Leguminosae	1	1		1	
Magnoliaceae	1	1	1		
Moraceae	1	1		1	
Myrtaceae	1	1		1	
Pentaphylacaceae	1	3		1	2
Phyllanthaceae	1	1			1
Pinaceae	2	2	2		
Primulaceae	1	1			1
Rosaceae	2	5	2	2	1
Rutaceae	2	2	1	1	
Salicaceae	1	1	1		
Sapindaceae	1	3	2	1	
Simaroubaceae	1	1			1
Symplocaceae	1	3		3	
Theaceae	1	1	1		
Thymelaeaceae	2	3			3
Total	48	77	29	28	20

LT: Large tree; *MT*: Medium tree; *ST*: Small tree

"B" (>20–≤40% frequency of occurrence), 3.1% belonged to class "C" (>40–≤60%), 2.1% belonged to class "D" (>60–≤80%), and 0.4% belonged to class "E" (>80–100%).

Table 10.3 Familial composition (count of species and genera) of herb and shrub layer in different forest types along the elevation gradient in Khangchendzonga National Park, Sikkim. The number of families was 50 for herbs, and 21 for shrubs

Family	Number of species	Number of genus
Herb layer		
Acanthaceae	1	1
Amaranthaceae	1	1
Apiaceae	3	3
Araceae	3	1
Araliaceae	3	3
Asparagaceae	4	3
Balsaminaceae	3	1
Begoniaceae	1	1
Berberidaceae	1	1
Boraginaceae	2	2
Brassicaceae	2	2
Campanulaceae	1	1
Caprifoliaceae	1	1
Caryophyllaceae	2	1
Commelinaceae	1	1
Compositae	17	12
Convolvulaceae	1	1
Cyperaceae	3	3
Dryopteridaceae	3	2
Equisetaceae	1	1
Euphorbiaceae	1	1
Gentianaceae	3	2
Geraniaceae	3	1
Hypericaceae	1	1
Hypoxidaceae	1	1
Juncaceae	1	1
Lamiaceae	3	3
Leguminosae	1	1
Liliaceae	1	1
Linaceae	1	1
Melanthiaceae	1	1
Melastomataceae	1	1
Nartheciaceae	1	1
Orchidaceae	1	1
Orobanchaceae	1	1
Oxalidaceae	2	1
Papaveraceae	1	1
Phrymaceae	1	1
Plantaginaceae	4	3
Poaceae	6	4

(continued)

Table 10.3 (continued)

Family	Number of species	Number of genus
Polygonaceae	10	4
Primulaceae	7	2
Pteridaceae	1	1
Ranunculaceae	6	5
Rosaceae	8	4
Rubiaceae	2	1
Saxifragaceae	3	3
Urticaceae	5	3
Violaceae	2	1
Zingiberaceae	1	1
Shrub layer		
Adoxaceae	2	2
Anacardiaceae	1	1
Berberidaceae	4	2
Cupressaceae	1	1
Ericaceae	11	4
Gleicheniaceae	2	2
Grossulariaceae	1	1
Hydrangeaceae	2	2
Lamiaceae	2	2
Leguminosae	1	1
Melastomataceae	3	3
Pentaphylacaceae	1	1
Poaceae	2	2
Polygonaceae	1	1
Primulaceae	2	1
Ranunculaceae	1	1
Rosaceae	7	5
Rubiaceae	4	4
Rutaceae	2	1
Thymelaeaceae	3	2
Urticaceae	3	3

10.3.4 Elevation Pattern of Species Richness

A significant decline in total number of species (including tree, shrub, and herb) was observed toward the higher end of elevation gradient (Fig. 10.5). Along the elevation gradient the tree species richness followed a reverse J-shaped curve and peaked at lower elevation (1700 m). The shrub and species richness followed exponentially random decline curve and peaked at 1900 m. Herb species richness followed random distribution with richness declined through the gradient and peaked at lower (1700 m) and mid (2900 m) elevation.

Table 10.4 Species richness, density, basal, area, and importance value index IVI of trees by different growth form in Khangchendzonga National Park, Sikkim

Growth form	Species		Density		Basal area		IVI	
	Number	%	ha^{-1}	%	m^2ha^{-1}	%	Value	%
Large tree	29	37.7	339.33	20.5	13.33	46.7	114.2	38.07
Medium tree	28	36.4	576.04	34.8	9.19	34.8	83.1	27.70
Small tree	20	26.0	739.91	44.7	4.88	18.5	102.7	34.23
Total	77	100	1655.28	100	27.4	100	300	100

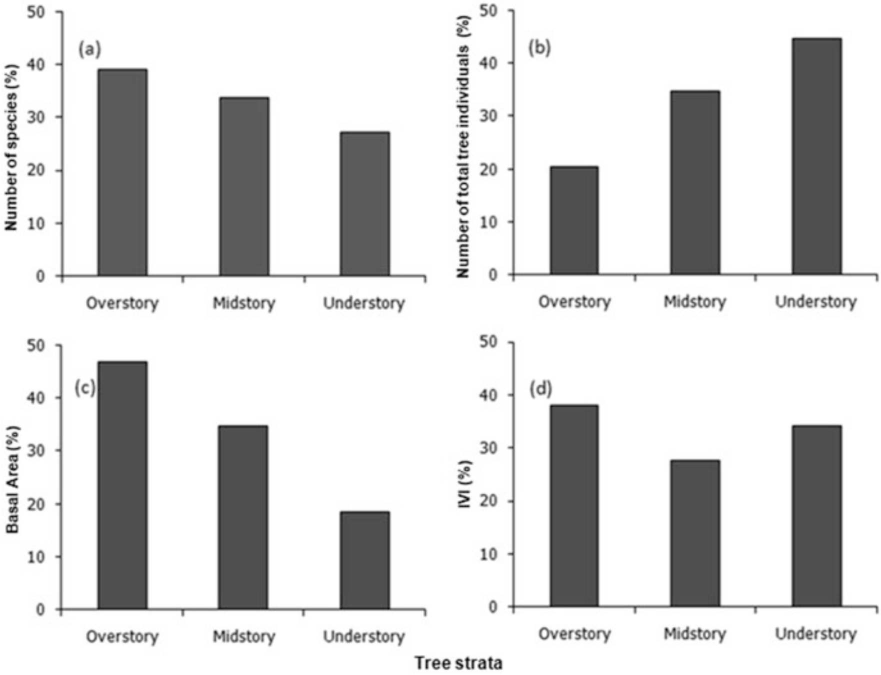

Fig. 10.2 Percentage of number of tree species, density, basal area, and IVI in different canopy layer structure in eastern Himalayan forests of Sikkim

10.3.5 Abundance (Tree Density and Basal Area) along the Elevation Gradient

The stand tree density (mean ± SD; 1655.2 ± 309 individuals/ha) varied significantly ($P < 0.05$) along the studied elevation gradient, with significantly higher stand density (2615.6 individuals/ha; $P < 0.05$) at 1800 m in mixed-broad leaved forests and minimum (303.7 individuals/ha; $P < 0.05$) at treeline (4000 m) (Fig. 10.6). Total Basal Area (TBA) values (mean ± SD; 27.4 ± 4.52 m^2/ha) differed significantly ($P < 0.05$) along the elevation gradient ranging from 0.90 ± 0.51 m^2/ha

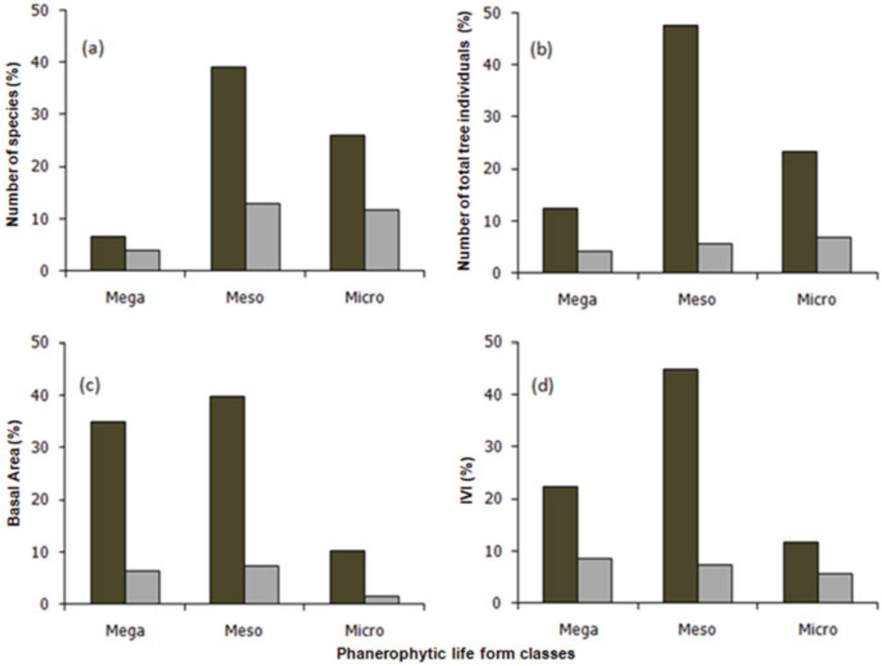

Fig. 10.3 Life-form spectrum of eastern Himalayan forests of Sikkim. The woody species were categorized into three phanerophytic classes: megaphanerophyte, mesophanerophyte, and microphanerophyte. The black bars indicate evergreen species and gray bars indicate deciduous species

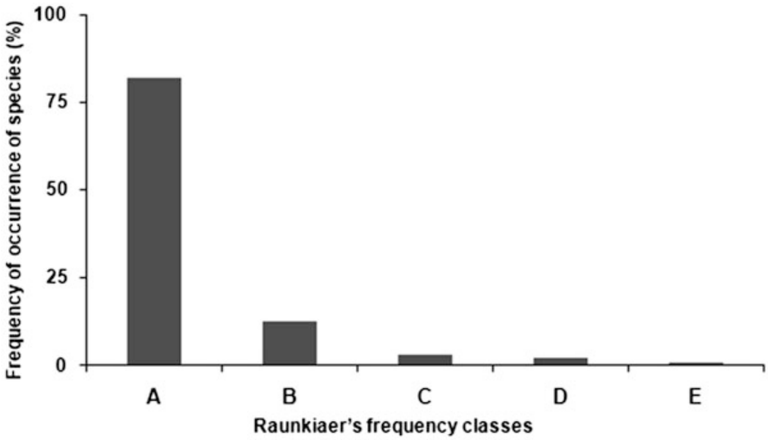

Fig. 10.4 Frequency of occurrence of species in subplots of 0.15 ha size, modeled on Raunkiaer's frequency classes in eastern Himalayan forests of Sikkim. Class "A" with ≤20% frequency of occurrence "B" (>20–≤40%), "C" (>40–≤60), "D" (>60–≤80), and "E" (>80–100%)

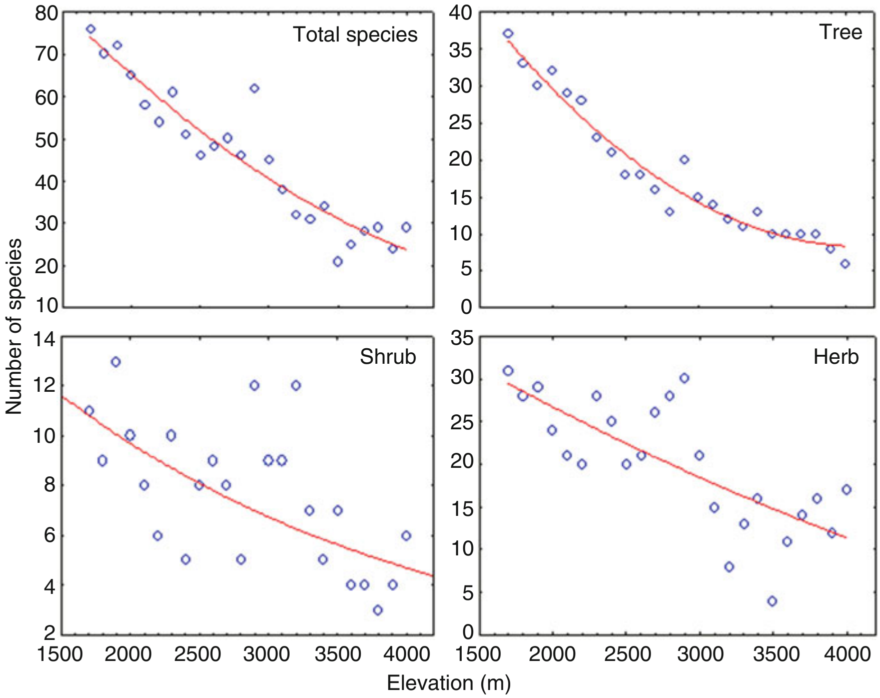

Fig. 10.5 Trends of species richness along the elevation gradient (1700–4000 m) in different growth form, in Khangchendzonga National Park, Sikkim

at treeline (4000 m) to 52.5 m^2/ha at 3200 m in *Abies* and *Tsuga* mixed communities (Fig. 10.6).

10.3.6 Species Diversity along the Elevation Gradient

The species diversity and dominance showed significant quadratic relation with elevation. The tree species diversity declined monotonically toward the higher elevation. The Shannon's diversity index (H') was 3.18 at 1700 m, whereafter it decreased continuing and was up to 1.21 at the treeline at 4000 m (Fig. 10.7a). The Pielou's evenness or homogeneity index (E) decreased toward the higher elevation, and ranged from 0.671 to 0.882 (Fig. 10.7b). The species dominance increased with increase in elevation and the Simpson's dominance index (D) ranged from 0.011 at 1700 m to 0.882 at 4000 m.

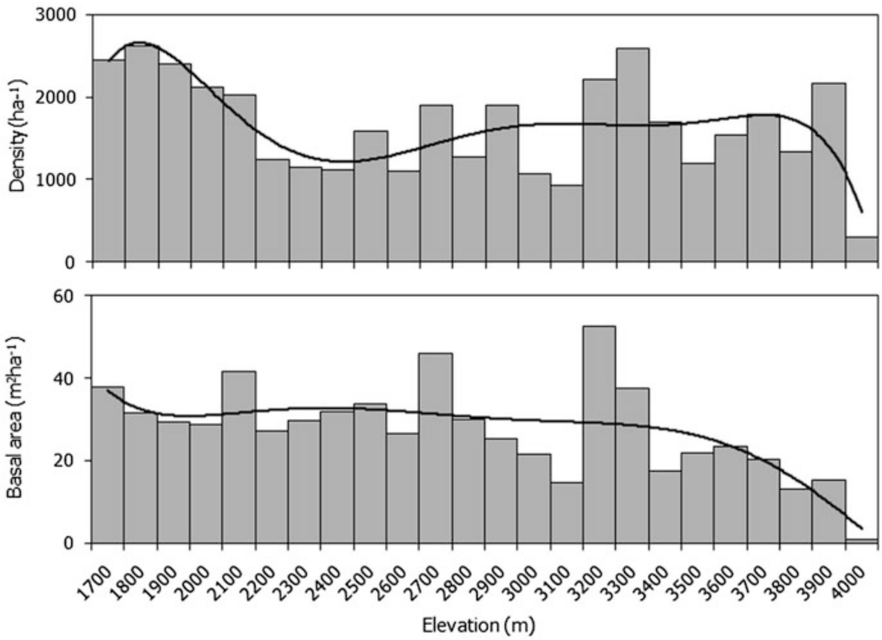

Fig. 10.6 Changes in density and basal area of tree species along the elevation gradient (1700–4000 m) in Khangchendzonga National Park, Sikkim

10.4 Discussion

Understanding species diversity and distribution patterns along the elevation gradient is important for helping managers to evaluate the complexity as well as the prospects of Himalayan forest ecosystems. In this study, we recorded 77 tree species, 56 shrub species, and 134 herb species in Sikkim, indicating the richness of the region. The abundance of herb species has also reported by Manish et al. (2016) and Sharma et al. (2019) for Sikkim Himalaya. Overall, this study recorded (including tree, shrub, and herb species) 81 families belonging to 267 species and 174 genera, in which Ericaceae was the most speciose family with 25 species. Out of the total 81 recorded families 37 were monotypic. Whereas Asteraceae (49 species) is reported to be the most speciose family with 28 monotypic family recorded in the Western Himalayan forests of India (Sharma et al. 2014), and Fagaceae (27) was the most speciose family with 49 monotypic family in the Eastern Himalayan forest of Arunachal Pradesh (Saikia et al. 2017). This difference can be related to the variation in terms of growth forms, species composition, climatic condition, and study area, as trees and shrubs are more dominant in the Eastern Himalayan region, whereas herbaceous species are dominant in the Western Himalayan region of forests.

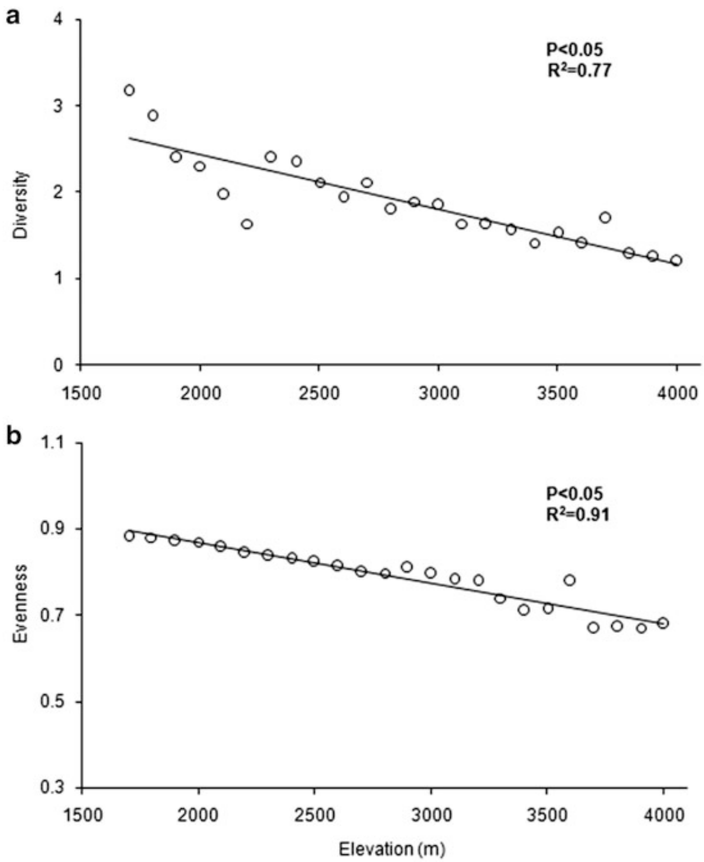

Fig. 10.7 Relationship between elevation and tree species diversity were: (**a**) Shannon index of diversity (*H′*); and (**b**) Pielou's evenness or homogeneity index (*E*)

In Sikkim, Acharya et al. (2011) reported the tree density of 965 individuals ha^{-1}) at elevation ranging from 300 to 4700 m, which is lower with the recorded tree density (1655.2 individuals/ha) in this study from mixed-broad leaved forest to most alpine scrub (1700–4000 m). The tree density values for Sikkim, are comparatively higher than that of Arunachal Pradesh, (456 individuals/ha), ranging 87–4161 m elevation (Saikia et al. 2017), western Himalayan (728 individuals/ha) subalpine forests (Gairola et al. 2015), and (546–616 individuals/ha) different ridge top forests of Uttarakhand west Himalayan region (Sharma et al. 2017). This difference in tree density can be attributed to the forest community structure, age class, site history, on site condition, and other factors (Parthasarathy 2001; Kumar et al. 2006). In the present study, the tree density showed irregular trend along the elevation gradient and higher value was recorded at 1800 m (2615.6 individuals/ha) in mixed-broad leaved forests and at 3300 m (2586.7 individuals/ha) in conifer dominated forests. This may be due to high regeneration potential of mixed-broad leaved forests (Paul et al. 2018) and less vulnerability to herbivory for conifer dominated forests (Begon et al. 2006). The mean basal area (27.4 ± 4.52 m^2/ha) of tree species in our study is lower than the reported basal area (72.1 ± 69.8 m^2/ha) in other parts of Sikkim (Acharya et al. 2011). These differences in the basal area may be attributed to altitudinal variations, species composition, population structure, and successional stage of the forests (Swamy et al. 2000). The maximum basal area was observed between mid elevation oak-dominated (45.9 m^2/ha at 2700 m) and conifer mixed (52.5 m^2/ha at 3000 m) forests, and it's attributed to the presence of large sized tree species in these forests.

Along the elevation gradient, we documented 77 tree species and the number of tree species declined with increasing girth size. Similar trends are exhibited by various taxa along the elevation gradients in the mountain regimes studied elsewhere (Graham 1990; Gaston 1996; Cardelus et al. 2006; Acharya et al. 2011; Saikia et al. 2017; Pandey et al. 2018b). Because of restricted resilience to climatic variations, many tree species are unable to expand their ranges beyond certain elevation range (Jetz and Rahbek 2002). Further, factors such as habitat availability, competition, dispersal and establishment ability, abundance, climatic tolerance, and historical incidences are the determinant factors of species range limit (Gaston 1996). The tree species richness along the elevation gradient exhibited a hump-shaped distribution pattern, which is usual pattern in the Indian Himalayan region (Behera and Kushwaha 2007; Acharya et al. 2011; Saikia et al. 2017; Pandey et al. 2018b). Our study showed the similar trend, thus confirming hump-shaped distribution pattern of tree species richness along the elevation gradient in Sikkim Himalaya region. This finding is supported by other studies in the forests of eastern Himalayan region of India (Behera and Kushwaha 2007; Acharya et al. 2011; Saikia et al. 2017; Sharma et al. 2019). Acharya et al. (2011) reported peak in tree species richness in Sikkim, at 1500 m and then abrupt decrease in richness till 3800 m. The Shannon's diversity index (H') is generally high in tropical forests of the Indian subcontinent and ranges from 0.81 to 4.1 (Singh et al. 1984; Parthasarathy et al. 1992; Bhuyan et al. 2003). The Shannon's diversity values for tree species in this study ranged between 1.2 and 3.2, which is slightly higher than that of the temperate forests of western Himalaya (Gairola et al. 2011; Dar and Sundarapandian 2016; Singh et al. 2016). The tree species diversity decreased with increasing elevations, which was in accordance with the earlier reports in the western Himalaya (Sharma et al. 2009; Singh and Kaushal 2006) and eastern Himalaya (Saikia et al. 2017).

One of the notable features of the present transect of Sikkim was that canopy was broken and undercanopy layers were continuous. On an average canopy tree density was 20.51% and undercanopy density was 79.51% of total density. It seems that the well-developed undercanopy did not allow canopy species to regenerate adequately. It is also possible that once canopy trees are uprooted or damaged the undercanopy layer thickens, making canopy regeneration difficult. The subtropical to temperate forests of Sikkim Himalaya exhibited a phanerophytic life-form spectrum. Among the woody life forms (≥10 gbh), the mega- and mesophanerophytes are predominant, and share up to 83% value of IVI, whereas the microphanerophytes contribute more species richness than IVI. These patterns of life-form spectrum substantiate with the other observation by Champion and Seth (1968), Whitmore (1984), and Shankar and Tripathi (2017) in various part of Indian subcontinent.

10.5 Conclusion

This study analyzes the floristics and phytosociological attributes along an elevation range of 1700–4000 m at 100 m elevation steps in eastern Himalaya forests of Sikkim. Species richness patterns of various growth forms were studied in the forests communities, ranging from broad-leaved forests (1700 m) to treeline ecotone (4000 m), which include 267 species from 174 genera and 81 families. The three layers of trees: (1) understory layer of low girth size trees, (2) canopy layer of *Betula* spp., *Vitex quinata*, *Rhododendron* spp., at higher elevation and *Prunus* spp., *Alnus nepalensis*, and *Eurya* spp. at middle elevation and (3) emergent layer of *Abies densa* and *Tsuga dumosa* at higher elevations and *Engelhardtia spicata, Castanopsis* spp., and *Lithocarpus* spp. at middle elevations. The total basal area was highest in middle elevations. The overall species richness declined monotonically with elevation. The reduction in tree height and richness along the elevation gradient is due its greater sensitivity to low temperature, dispersal and establishment abilities, and liquid water availability. Climatic and anthropogenic factors, which are not evaluated in this study, might influence for species diversity pattern along the elevation gradients in the forests of eastern Himalaya. A sparse canopy layer and continuously dense undercanopy layer and overall high tree density are the characteristics of the study forests.

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