Tropical Ecology **59**(2): 259–271, 2018 ISSN 0564-3295

www.tropecol.com

Changes in vegetation attributes along an elevation gradient towards timberline in Khangchendzonga National Park, Sikkim

ASEESH PANDEY, SANDHYA RAI & DEVENDRA KUMAR*

G.B. Pant National Institute of Himalayan Environment and Sustainable Development, Sikkim Regional Centre, Pangthang, Gangtok 737101, Sikkim, India

Abstract: In this preliminary elevation gradient (3000–4000 m) study of high ranges forest of Sikkim (eastern Himalayas), we have analyzed the (i) species composition, (ii) tree species richness, density, basal area and distribution range, and (iii) forest structure by diameter at breast height (DBH) classes. The main purpose was to identify the role of elevation in tree dominance, and species richness in the subalpine forests of eastern Himalaya. The study was conducted in the Yuksam-Dzongri transect nested within the Khangchendzonga National Park, west district of Sikkim state. The quadrat method was used to sample vegetation and sampling was done at every 100 m steps between 3000 m and 4000 m elevations, eventually ending up in the timberline ecotone. A total of 109 species belonging to 80 genera and 46 families were recorded. The species richness and total tree basal area (TBA) declined monotonically along the elevation gradient. Tree density in present elevation transect was significantly higher than its western Himalayan counter parts of Indian Himalayan region. The presence of 23 tree species in the highest 1000 m forested zone highlights the high tree species richness of the eastern Himalaya. It was largely because of the speciation of *Rhododendron* spp. Further investigation is required to develop a holistic understating of these vegetation patterns across the Indian Himalayan region.

Key words: Distribution range, eastern Himalaya, elevation gradient, forest structure, subalpine forest.

Guest editor: S.P. Singh

Introduction

Worldwide, the effects of global climate change on ecosystems have been of increasing concern (Christensen *et al.* 2007), and studies have indicated ecological fingerprints of recent global warming across a wide range of habitats (Root *et al.* 2003; Walther *et al.* 2002) and vegetation (Pauli *et al.* 2012). In a warming world, species are expected to shift their distributions pole-ward in latitude and upward in elevation (Walther *et al.* 2002). At global scale, studies are witnessed on elevational expansion of the forest line in many mountain ranges, including the Polar Urals, Russia (Devi *et al.* 2008), the central Swiss Alps, Switzerland (Vittoz *et al.* 2008), western Himalaya, India (Panigrahy *et al.* 2010), Rocky Mountains, Southern Alberta (Cullen & Marshall 2011), and the central Himalaya, Nepal (Gaire *et al.* 2014). This upward forest expansion is expected to shrink the extent of the alpine ecosystems and, possibly cause species loss and ecosystem degradation through greater fragmentation (Forrest *et al.* 2012; Macias-Fauria & Johnson 2013; Peel *et al.* 2007; Randin *et al.* 2009). To understand the impacts of climate change on patterns of vegetation distribution and conser-

**Corresponding Author*; e-mail: devendrawii@gmail.com

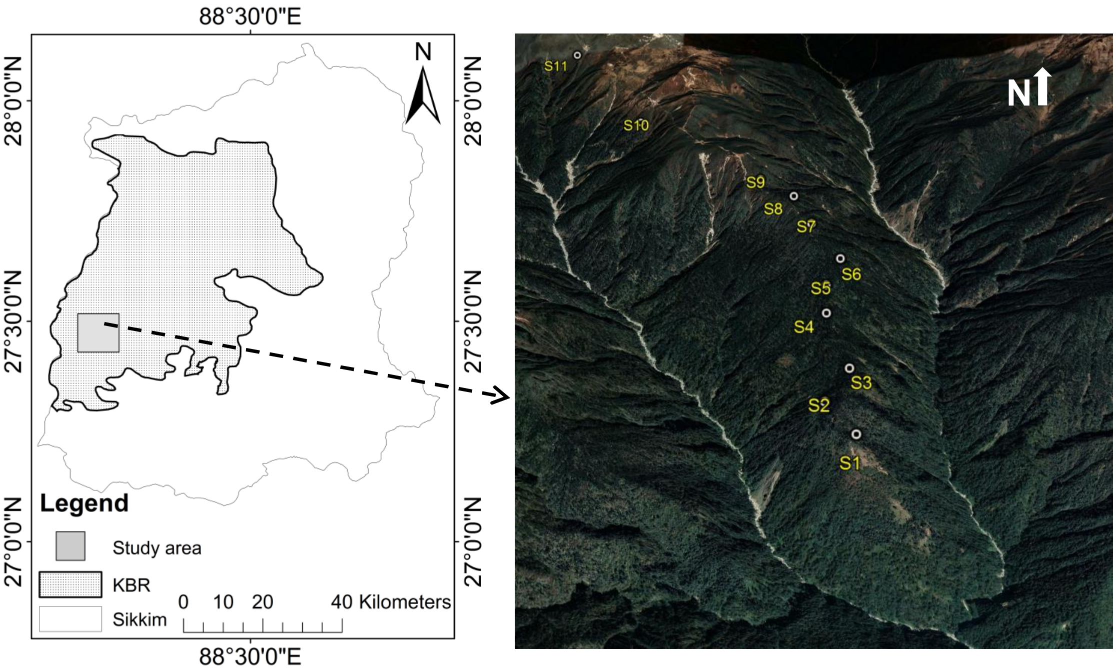

Fig. 1. Study area map of subalpine forest in Khangchendzonga National Park, West Sikkim. S denotes sites at different elevation gradients. (The Inset Map source: Google Earth)

vation of biological diversity, knowledge of the biogeographical variation in species richness is critical (Vetaas & Grytnes 2002). In mountain ecosystems, species richness varies along the elevation gradients which can be used to study the trends of vegetation responses under the changing climate scenario.

The elevation gradient in Himalayas is one of the longest bioclimatic elevation gradients in the world and sustains rich biological diversity, within only a stretch of 150 km one can move from a tropical zone to a zone of permanent frost. These climatic, topographic, geological, and altitudinal variations have created unique landscapes, ecosystems, and biota in the Himalayas. The eastern Himalaya (EH), stretching from eastern Nepal to Yunnan in China, between 82.70°E and 100.31°E longitude and 21.95°N and 29.45°N latitude, covers an area 524,190 km^2. States of north-eastern region of India fall under this region and shares (52.03%) of the total EH region (Tse-ring *et al.* 2010). Sikkim Himalaya, due to its complex topography and highly diverse biological system (Acharya *et al.* 2011) offers an excellent opportunity to address the questions dealing with vegetation community and species response to the climate change.

Of the 825 ecoregions in the world (Olson & Dinerstein 2002), 13 are present across the Himalayan arc (Shrestha *et al.* 2012), and 5 are represented in the Sikkim. Among them, the Eastern Himalayan sub-alpine forests represent the transition (ecotone) from the forested ecoregions to treeless alpine meadows and boulder-strewn alpine screes (Olson *et al.* 2001). Besides functioning as a potential indicator for trends of climatic change, this ecotone is valued as a unique habitat for representative, specialized and sensitive biodiversity elements including distinct biological assemblages, native and endemic floral and faunal species, and economically important species (Dhar 2000; Rawal & Dhar 1997). A few elevation gradient studies with focus on plant diversity patterns along elevational gradients have been made in the Central Himalaya (Bhattarai & Vetaas 2006; Bhattarai *et al.* 2004; Carpenter 2005; Grau *et al.* 2007; Vetaas & Grytnes 2002), in the Western Himalaya (Gairola *et al.* 2015; Oommen & Shanker 2005; Sharma *et al.* 2009; Sharma *et al.* 2010) in the Eastern Himalaya (Acharya *et al.* 2011; Behera & Kushwaha 2007).

The present study is aimed to understand and analyse the patterns of vegetation structure, species composition, and distribution along an elevation gradient leading to timberline ecotone in eastern Himalayan sub-alpine forests. It gives a preliminary account of changes in species diversity and species population dynamics in response to changing climate along a 1000 m elevation range between 3000–4000 m.

Materials and methods

Study area

The study was conducted in the Khangchendzonga National Park (KNP) in the Sikkim state of India (Fig. 1). The KNP landscape [area: 1784 km^2; location: between 27°03'41" and 28°7'34" N latitude and, 88°03'40" and 88°57'19" E longitude; elevation: 100 m asl (foothill) to 8548 m asl (Mount Khangchendzonga peak)] is famous for its rich biodiversity, extreme topographic variations, and alpine and sub-alpine ecosystems. The Sikkim is a well-recognized biodiversity hotspot area, and KNP is recently inscribed as the first mixed world heritage sites of India by UNESCO (http://whc.unesco.org/en/newproperties).

The present study area largely comprises sub-alpine forests of mountainous landscape of the Mount Khangchendzonga (India), ranging from 3,000 m above sea level to the elevation limit of the forest (timberline) in Yuksam-Dzongri transect, nested in KNP. This area falls under moist pre-monsoon and dry winter precipitation regime and receives 1021.0 ± 157.01 mm annual precipitation. The study area experiences 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. The climate data of the study area was procured from WorldClim dataset (Hijmans *et al.* 2005; http://www.worldclim.org/bioclim.htm). To understand the patterns of the vegetation and community structure, vegetation of the identified transect was surveyed in each 100 m elevation band up to the timberline (Fig. 1).

Vegetation sampling and data analysis

Three 0.1 ha plots (dimensions: 50 m × 20 m) were sampled in each 100 m elevational difference across the subalpine forests (3000–4000 m) of KNP landscape. In each 0.1 ha plot, five 10 m × 10 m quadrats were laid randomly for enumerating trees and saplings, and in each 10 m × 10 m quadrat one 5 m × 5 m sub-quadrat was laid randomly for enumerating shrubs/seedlings of tree species, and four 1 m × 1 m random quadrats to sample herbs. The sample plots were established and surveyed during May-June and September-October to avoid snow and heavy rain period. All individuals present within the quadrats were enumerated. Woody stems were measured for size and the circumference at breast height (CBH, *i.e.* 1.37 m above the tree base) for the determination of tree basal area, and in case of small-saplings and seedlings, it was taken at collar height and finally calculated as $(C)^2/4\pi$ (where C = mean circumference of a tree and π = 3.14). Thus, the total basal area (TBA) of each tree was calculated as the mean basal area of a tree × density. TBA values of the three plots of each elevational site were averaged to obtain the final TBA value for each site. Woody stems having ≥ 30 cm CBH were considered trees; individuals with 10 to 30 cm CBH as saplings; and those with CBH less than 10cm were considered as seedlings. The survey data were quantitatively analyzed to obtain the values of density, frequency, and total basal area (TBA) following Misra (1968) and Mueller-Dombois & Ellenberg (1974). Importance value index (IVI) was the sum of relative frequency, relative density and relative dominance (Phillips 1959) of a species. Density and TBA values were converted to per hectare (ha^{-1}) basis for extrapolation of the results. Total basal area (m^2 ha^{-1}) was used to determine the relative dominance of a tree species. Shannon diversity (H'), Simpson's index of Dominance (C), Margalef's Index of Species richness (S) and Shannon Index of species evenness (*E*) were computed following Magurran (1988). Species richness was determined as the total number of species in sampled area for different life forms. Analysis of variance (ANOVA) was used to compare the differences in means of important value index (IVI) of woody stems between different elevations and the significant differences were tested using the Duncan's multiple range test (DMRT; $P < 0.05$). Linear regression analysis was used to understand the linear/quadratic relationship between tree diversity and tree richness with elevational gradients.

Results

Elevation pattern of species composition

A total of 6,488 individuals were recorded in tree layer of which 2,483 were adult trees, 2,633 saplings, and 1,372 seedlings belonging to 10 families, 11 genera, and 23 species from the subalpine forest of KNP. Ericaceae was represented by 10 tree species i.e., *Lyonia villosa, Rhododendron arboreum, R. barbatum, R. decipiens, R. falconeri, R. fulgens, R. hodgsonii, R. lanatum, R. thomsonii* and *R. wightii*. The stand tree density (mean ± SE; 1,504 ± 209 individuals ha^{-1}) varied significantly ($P < 0.05$) along the elevation gradient,

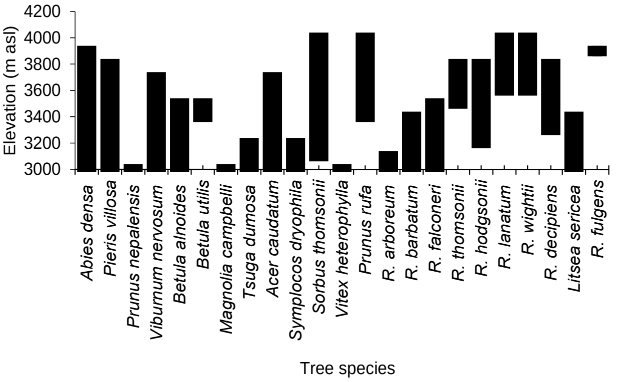

Fig. 2. Elevational range of tree species across the subalpine forest of Khangchendzonga National Park, Sikkim. *(R. = Rhododendron)*

with significantly higher stand density (2,593 individuals ha^{-1}; $P < 0.05$) in *Abies* dominated forest at the 3300 m and minimum stand density (307 individuals ha^{-1}; $P < 0.05$) at timberline (3989 m). The sapling density peaked (3,460 individuals ha^{-1}; $P < 0.05$) in *Tsuga* mixed forest, at the lower elevational end (3000 m) and seedling density peaked (6,293 individuals ha^{-1}; $P < 0.05$) in *R. hodgsonii* forest at the middle elevation 3600 m (Table 1). Among the tree species, the maximum density was observed for *R. hodgsonii* and minimum for *Lyonia villosa* (Table S1). Most of the tree species had shown the restricted distribution range and none of the species occurred all along the gradient (Fig. 2). The widest amplitude was observed for *A. densa* (3000–3900 m) and *Sorbus microphylla* (3100–3989 m). A few species, such as *Prunus bracteopadus* and *Magnolia campbellii* were confined to the lower end of the elevational transect, as these are species of temperate belt. In contrast *Rhododendron fulgens* was confined to the upper end of the forest range. Among the tall tree species, *A. densa* goes up, the highest formed forest patches above the timberline (Fig. 2). Small tree species like *Sorbus microphylla, Prunus rufa, R. lanatum*, *R. wightii*, were observed growing as under canopy of *A. densa* up to 3900 m, where after they formed small forest patches without the presence of *A. densa* up to 4000 m. Above 4000 m these species occurred as solitary individuals. Unlike to western Himalaya, where *Betula utilis* is the principal treeline species, in Sikkim *A. densa* along with the associated species mainly *R. wightii*, *R. lanatum* are the principal treeline species.

The TBA values (mean ± SE; 19.02 ± 4.57 m^2 ha^{-1}) differed significantly ($P < 0.05$) along the elevation gradient ranging from 0.93 ± 0.53 m^2 ha^{-1} at highest elevation site to 52.52 ± 14.53 m^2 ha^{-1} at low elevation (3200 m). Based on the important value index (IVI) of tree species separated by the Duncan's multiple range test (DMRT), the sampled area can be subdivided in to six different forest communities (AF: *Abies* dominated forest; RhF: *R. hodgsonii* forest; RSMF: *Rhododendron, Sorbus* mixed forest; RwF: *R. wightii* forest; TRMF: *Tsuga, Rhododendron* mixed forest; TVMF: *Tsuga, Viburnum* mixed forest) (Table 2).

In shrub layer, a total of 2,419 individuals belonging to 22 species, 17 genera, and 11 families were enumerated along the studied gradient (Table S2). Ericaceae was the most dominant family, represented by 9 species, followed by Rosaceae (3 species), and Berberidaceae (2 species). The mean shrub density (5,605 ± 1,097 individuals ha^{-1}) was observed significantly higher (12,747 individuals ha^{-1}; $P < 0.05$) at low elevation 3,200 m and decreased towards mid and high elevations. The species density was recorded maximum for *Rubus* sp. however, *Viburnum cotinifolium, Rhododendron camelliflorum* and *Mahonia napaulensis* shared minimum density values for the shrub layer.

In herbaceous layer, a total of 7,024 individuals of 64 species were recorded belonging to 53 genera and 29 families, in addition to 8 unidentified herb species. Compositae was the most dominant family represented by 7 herb species, followed by Polygonaceae, Primulaceae, and Rosaceae represented by 5 herb species each (Table S3). The density value for herb species significantly ($P < 0.05$) differed across the study area and a significantly higher density value (2,04,000 individuals ha^{-1}; $P < 0.05$) was recorded in mid-elevation (3,400 m) of *A. densa* dominated forest and (1,99,167 individuals ha^{-1}, $P < 0.05$) in *Tsuga, Rhododendron* mixed forest at low elevation (3000 m) (Table 1). The *Fragaria daltoni* emerged as the most dominant herb species with widest amplitude across the area (Table S3).

Diameter class distribution and elevational trend of growth forms

The diameter class wise distribution of tree species richness, and total basal area (TBA) along different elevational ranges (high, middle and low) represented reverse J-shaped, interrupted reverse J-shaped, and hump shaped patterns (Fig. 3a–c). Overall the TBA peaked at 3200 m in *A. densa* dominated forest (Fig. 4). Among the life-forms, tree density peaked in *A. densa* dominated forest

Table 1. Patterns of vegetation composition along the elevational gradient in subalpine forest of Khangchendzonga National Park, Sikkim.

Forest Communities	Elevation (m asl)	TBA (m^2 ha^{-1})	Tree density (Individuals ha^{-1})	Sapling density (Individuals ha^{-1})	Seedling (Individuals ha^{-1})	Shrub density (Individuals ha^{-1})	Herb density (Individuals ha^{-1})
TRMF	3000	4.99±1.70cd	1073.33±179.75cd	3460.0±120.554a	2533.3±1239.64bcd	9946.67±765.01ab	199166.67±24251.0a
TVMF	3100	3.27±0.99cd	606.67±173.72de	720.0±257.16de	1840.0±697.42bcd	2480.0±454.89d	98166.67±5833.33bc
AF	3200	52.52±14.53a	2220.0±196.98ab	1880.0±522.047b	4613.33±515.02ab	12746.67±943.89a	34833.33±12125.5c
AF	3300	37.25±9.51ab	2593.3±81.10a	2780.0±220.0a	3200.0±922.61abcd	9146.67±933.33b	79333.33±23566.1bc
AF	3400	17.60±1.65bcd	1700.00±87.18bc	1993.33±213.65b	3120.0±561.9abcd	7173.33±986.67bc	204000.0±25059.93a
AF	3500	20.96±6.02bcd	1186.67±256.21cd	953.33±206.67cde	4400.0±697.42ab	5493.33±1326.92cd	19833.33±1092.9c
RhF	3600	23.06±3.19bc	1553.33±127.19bc	1413.33±198.77bcd	6293.3±2145.8a	2533.33±1365.74d	75666.67±37251.8bc
RhF	3700	20.37±6.38bcd	1813.33±213.33bc	1586.67±373.51bc	2373.3±907.84bcd	2693.33±1554.23d	92333.33±40270.27bc
RSMF	3800	13.17±1.42cd	1340.0±254.03c	1240.0±280.0bcd	4000.0±1883.54abc	4000.0±1019.28cd	159166.67±26461.2ab
AF	3900	15.06±3.05cd	2146.67±497.64ab	1220.0±61.10bcd	740.0±174.36cd	3253.33±1755.35d	80666.67±26032.6bc
RwF	4000	0.93±0.53d	306.67±177.51e	360.0±94.52e	313.33±52.07d	2186.67±232.47d	127500.0±39585.35ab
Average		19.02±4.57	1,504±209	1,601±272	3,036±529	5,605±1097	1,06,424±18,236

Values representing the mean±SE, mean values within each column (elevation sites) followed by same letters are not significantly ($P < 0.05$) different, separated by Duncan's Multiple Range Test (DMRT). Forest communities-AF: *Abies* dominated forest; RSMF: *Rhododendron, Sorbus* mixed forest; RhF: *Rhododendron hodgsonii* forest; RwF: *Rhododendron wightii* forest; TRMF: *Tsuga, Rhododendron* mixed forest; TVMF: *Tsuga, Viburnum* mixed forest.

Table 2. Patterns of forest communities along the elevation gradient in subalpine forest of Khangchendzonga National Park, Sikkim.

Tree species	TRMF (3000 m asl)	TVMF (3100 m asl)	AF (3200 m asl)	AF (3300 m asl)	AF (3400 m asl)	AF (3500 m asl)	RhF (3600 m asl)	RhF (3700 m asl)	RSMF (3800 m asl)	AF (3900 m asl)	RwF (4000 m asl)
Abies densa	11.65± 7.05bc	19.34± 12.16bc	109.57± 4.62a	85.16± 8.33a	92.50± 9.74a	126.93± 3.12a	102.98± 3.83b	54.85± 23.43b	51.21± 14.80ab	122.55± 27.27a	-
Acer caudatum	20.78± 2.99bc	50.19± 18.99ab	20.25± 5.28d	39.43± 5.65c	15.54± 1.81cd	-	4.27± 4.27d	10.19± 1.36c	-	-	-
Betula alnoides	19.96± 6.06bc	-	6.88± 3.58ef	15.70± 1.94d	26.03± 1.07c	3.75± 3.75e	-	-	-	-	-
Betula utilis	-	-	-	-	5.54± 0.21de	12.03± 8.14d	-	-	-	-	-
Litsea sericea	-	7.71± 7.71bc	-	-	19.26± 11.89c	-	-	-	-	-	-
Lyonia villosa	6.17± 3.63c	-	-	-	-	-	-	-	2.09± 2.09e	-	-
Magnolia campbelli	7.66± 7.66c		-	-		-	-	-	-	-	-
Prunus bracteopadus	13.79± 3.12bc	-	-	-	-	-	-	-		-	-
Prunus rufa	-	-	-	-	-	3.29± 3.29e	9.89± 5.75d	17.57± 13.11c	29.43± 14.20bcd	14.75± 14.75bc	58.46± 30.60b
Rhododendron arboreum	50.07± 18.49a	16.53± 16.53bc	-	-	-	-	-	-	-	-	-
Rhododendron barbatum	1.80± 1.80c	9.97± 8.94bc	59.66± 4.31b	30.22± 5.64c	24.10± 7.10c	-	-	-	-	-	-
Rhododendron decipiens	-	-	-	6.96± 12.14d	4.50± 2.35de	-	-	2.82± 2.82c	6.96± 6.96de	-	-
Rhododendron falconeri	56.29± 16.14a	45.11± 6.56abc	47.32± 2.12c	-	-	-	-	-	-	-	-
Rhododendron fulgens	-	-	-	-	-	-	-	-	-	0.43± 0.43c	-

Contd...

Table 2. Continued.

Tree species	TRMF (3000 m asl)	TVMF (3100 m asl)	AF (3200 m asl)	AF (3300 m asl)	AF (3400 m asl)	AF (3500 m asl)	RhF (3600 m asl)	RhF (3700 m asl)	RSMF (3800 m asl)	AF (3900 m asl)	RwF (4000 m asl)
Rhododendron hodgsonii	-	-	-	68.49± 13.04b	79.80± 9.64b	95.71± 3.90b	125.38± 2.19a	103.23± 12.36a	66.85± 6.83a	-	-
Rhododendron lanatum	-	-	-	-	-	-	5.63± 5.63d	16.74± 9.85c	27.10± 7.30cd	82.53± 23.19b	14.52± 14.52c
Rhododendron thomsonii	-	-	-	-	-	-	9.38± 5.36d	12.04± 7.12c	39.09± 10.06bc		
Rhododendron wightii	-	-	-	-	-	-	2.65± 2.65d	5.51± 2.85c	9.52± 5.92de	40.75± 13.75b	178.11± 20.94a
Sorbus microphylla	-	5.51± 5.51c	9.12± 4.74e	7.32± 0.85d	2.31± 2.31de	13.67± 7.56d	27.61± 5.82c	64.88± 17.99b	67.77± 22.56a	39.00± 34.39b	48.91± 28.47b
Symplocos dryophila	38.28± 7.89ab	14.97± 14.97bc	-	-	-	-	-	-	-	-	-
Tsuga dumosa	54.48± 25.74a	66.98± 46.17a	1.73± 1.73f	-	-	-	-	-	-	-	-
Viburnum nervosum	6.89± 3.62c	63.69± 27.44a	20.92± 3.72d	30.71± 10.46c	24.77± 1.91c	45.86± 3.28c	12.21± 12.21d	12.16± 9.01c	-	-	-
Vitex quinata	12.19± 12.19bc	-	24.54± 2.24d	12.42± 7.99d	5.65± 5.65de	-	-	-	-	-	-

Values representing the mean±SE, mean values within each column (elevation sites) followed by same letters are not significantly ($P< 0.05$) different, separated by Duncan's Multiple Range Test (DMRT). The tree IVI values followed by the letter 'a' in each elevation site indicates the significantly higherdominance of species. Forest communities-AF: *Abies* dominated forest; RSMF: *Rhododendron, Sorbus* mixed forest; RhF: *Rhododendron hodgsonii* forest; RwF: *Rhododendron wightii* forest; TRMF: *Tsuga, Rhododendron* mixed forest; TVMF: *Tsuga, Viburnum* mixed forest.

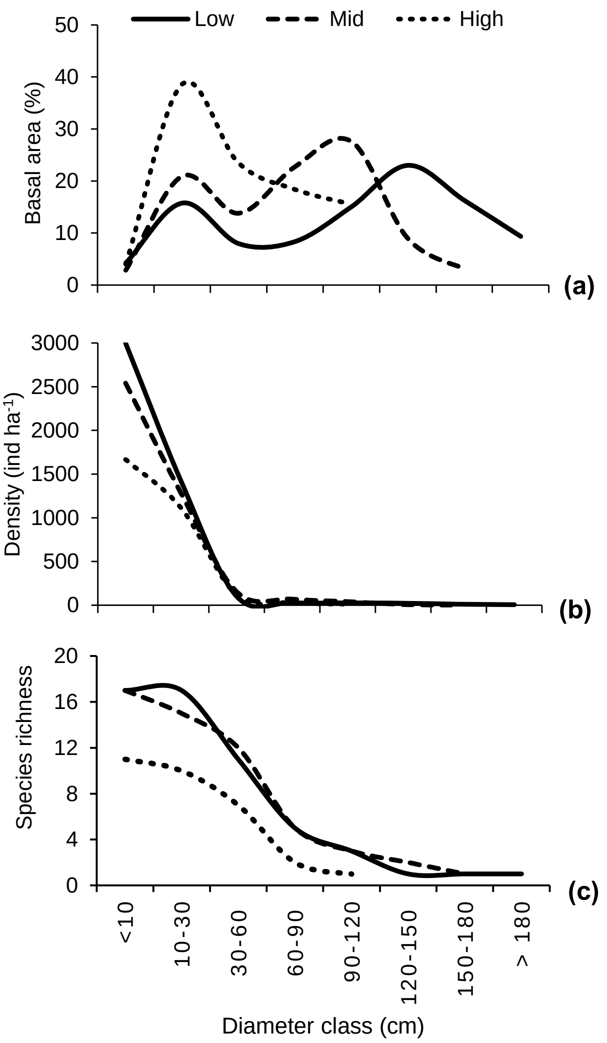

Fig. 3. Tree species richness, density and percent basal area by DBH classes (cm) at different altitudes (Lower 3000–3300 m; Middle: 3400–3700 m asl; Higher: 3800–4000 m asl). The diameter class < 10 cm (CBH: < 30 cm) includes seedlings and saplings.

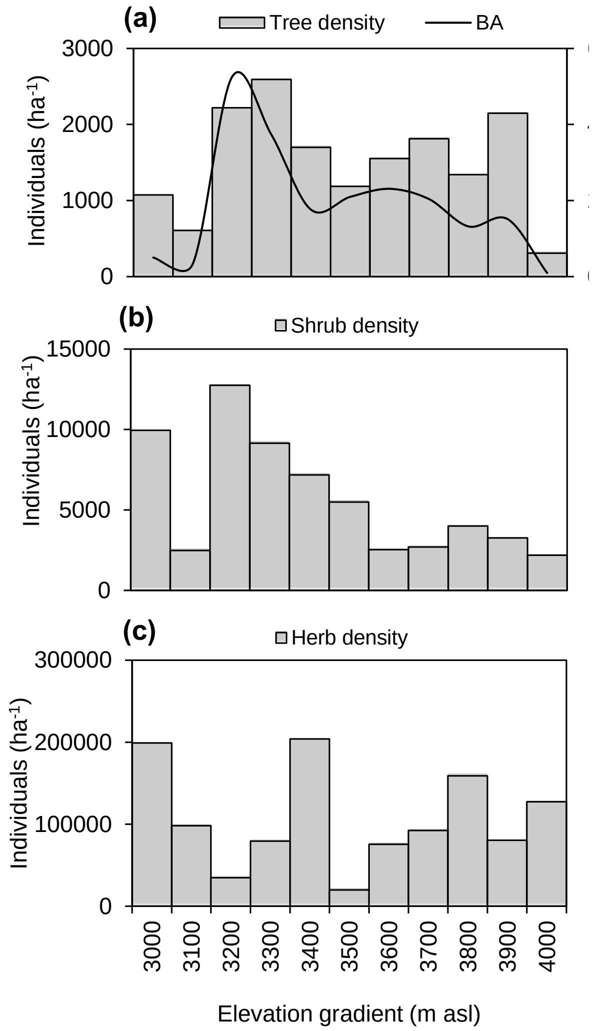

Fig. 4. Elevational trends of different growth forms in subalpine forest of Khangchendzonga National Park, Sikkim.

at lower elevation (3300 m), and shrub density also peaked in *A. densa* dominated forest at lower elevation (3200 m). However the herb density peaked in both *Tsuga, Rhododendron* mixed forest at 3000 m and *A. densa dominated* forest at 3400 m (Fig. 4).

The total species richness (including herb, shrub and tree) followed a reverse J–shaped pattern along the elevation gradient. A significant decline in species number was observed towards the higher end of the elevation gradient. Regression drawn between species richness and elevation showed a significant quadratic relation ($R^2 = 0.74$, $P < 0.01$). Species richness of trees followed a hump-shaped relationship with elevation, showing a peak at around 3400 m. Shrub species richness followed a reverse J shaped curve and peaked at 3200 m. The herb species richness followed a reverse hump shaped curve and species richness declined towards mid-elevation (Fig. 5).

The relationship between elevation and tree species composition

Regression drawn between elevation and tree species composition (Shannon diversity and Margalef's index of species richness) showed a significant quadratic relation (Fig. 6). The tree species diversity declined monotonically with elevation. The

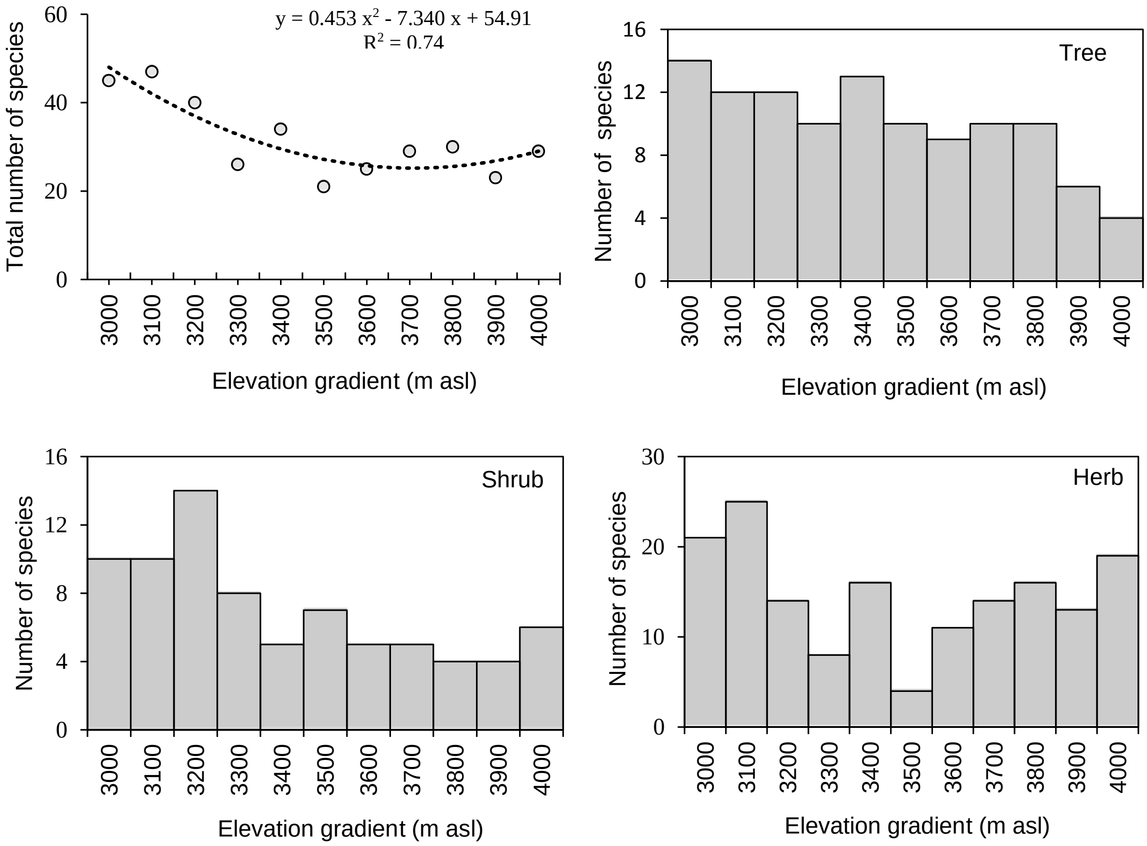

Fig. 5. Trends of species richness along the elevation gradient in subalpine forest of Khangchendzonga National Park, Sikkim.

Shannon diversity (H') was 1.86 at the 3000 m, which gradually decreased up to 1.26 for near timberline forest 3900 m, and reached finally up to 1.44 at the timberline forest 4000 m. Species evenness did not vary significantly along the gradient and the Shannon's index of species evenness value was observed between 0.68–0.88. The species richness showed a significant decreasing trend towards the higher elevation and the Margalef's index values of species richness varied between 10.82 at 3000 m to 5.06 at the timberline forest (4000 m) (Fig. 6). The dominance increased with an increase in the elevation and Simpson's index value was 0.22 at 3000 m which gradually increased towards the higher elevations.

Discussion

In Sikkim along the elevation gradient, the maximum tree density (1,675 individuals ha^{-1}) is reported between 2800–3800 m (Acharya *et al.* 2011), which is comparable with the recorded tree density (1,504 ± 209 individuals ha^{-1}) in the present study from the subalpine forest (3000–4000 m). However, the tree density values of Sikkim Eastern Himalaya are comparatively higher than the western Himalayan (728 individuals ha^{-1}) subalpine forests (Gairola *et al.* 2015), and (546–616 individuals ha^{-1}) different ridge top forests of Uttarakhand west Himalaya (Sharma *et al.* 2017). This variation in tree density can be attributed to the forest community type, forest age, site history and site condition (Parthasarathy 2001; Kumar *et al.* 2006). The tree density in present study showed an irregular trend along the elevation gradient and the maximum tree density was recorded from *Abies* dominated forests which can be correlated to their high regeneration potential and less vulnerability to herbivory (Begon *et al.* 2006). Further, the presence of *Rhododendron* spp. in under-canopy makes these forests denser. These dense canopies help to retain the moisture, which supports the establishment of shade adapted seedlings. However, the density values for shrub and herb species in the present study area are slightly higher than the western Himalayan subalpine forests

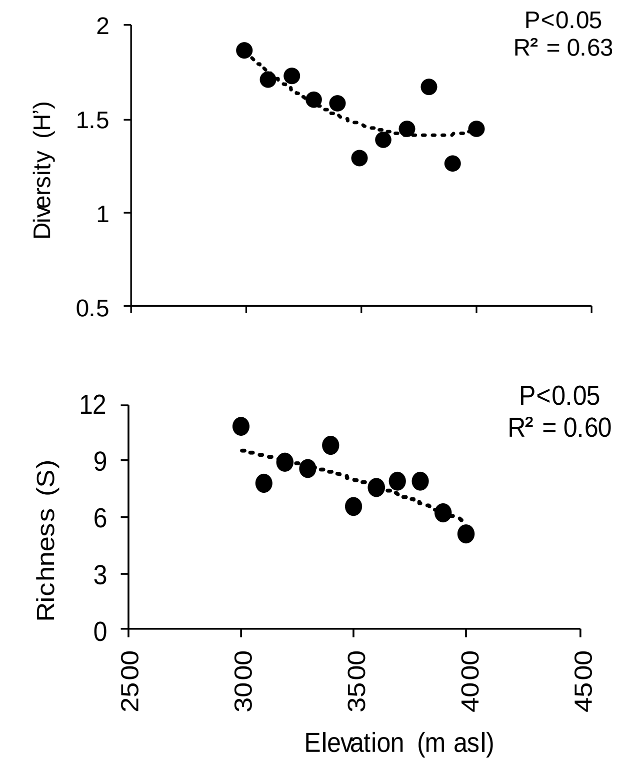

Fig. 6. Relationship between elevation and tree species composition were; H′: Shannon index of diversity; S: Margalef's Index of Species richness.

(Gairola *et al.* 2015) and significantly lower than the eastern Himalayan forests in Arunachal Pradesh, north-eastern region of India (Saikia *et al.* 2017). Overall, the present study recorded Ericaceae as the most dominant family with 19 spp., where as Compositae was the dominant family in the Western Himalayan forests of India (Sharma *et al.* 2014) and Fabaceae was the most species rich family in eastern Himalayan forests in Arunachal Pradesh, Northeast India (Saikia *et al.* 2017). This difference can be related to the variations in growth forms, species composition, and study area, as the study area is rich in *Rhododendron* spp. and contributes to both tree (9 spp.) and shrub (5 spp.) layers.

The mean basal area (19.02 ± 4.57 m^2 ha^{-1}) of 6,488 individuals of tree species in present study was found lower than the reported basal area (72.1 ± 69.8) of 3,874 individual trees species between 300–4700 m elevations in other parts of Sikkim (Acharya *et al.* 2011). This variation in the basal area may be attributed to altitudinal variations, species composition, age structure and successional stage of the forest (Swamy *et al.* 2000). The present study covers the area of subalpine forest (3000–4000 m) and consists of the high density of low girth class tree species such as rhododendrons in understory layer. However, the TBA value of present study (0.93–52.52 m^2 ha^{-1}) is comparable with various sub alpine forests of Uttarakhand west Himalaya such as Nanda Devi Biosphere Reserve (2300–3800 m asl) 14.68–80.28 m^2 ha^{-1} (Joshi & Samant 2004), Valley of Flower National Park (2750–3250 m asl) 17.87–86.75 m^2 ha^{-1} (Gairola *et al.* 2015), and Tungnath (3000–3200 m asl) 8.94–69.84 m^2 ha^{-1}; Lata (3000–3200 m asl) 15.29–35.33 m^2 ha^{-1}; Pindari (3000–3200 m asl) 16.75–37.16 m^2 ha^{-1} (Gairola *et al.* 2014).

A total of six forest types (communities) were observed along an elevation gradient, among them *A. densa* dominated forest community was the most common and represented by 5 elevation sites. In the present study, we documented 23 tree species and the number of species declined with increasing girth size. Similar trend was exhibited by various taxa along elevational gradients in the mountain ecosystems (Acharya *et al.* 2011; Cardelus *et al.* 2006; Gaston 1996; Graham 1990). This posits narrow tolerance to climatic variations by the species, therefore unable to extend their ranges beyond certain elevation range (Jetz & Rahbek 2002). Further, the factors like habitat availability, seed dispersal and establishment abilities, competition, local abundance, climatic or environmental tolerances and historical incidences are the determinants of species range limit (Gaston 1996).

The relationship between species richness and evenness across communities remains an unsettled issue in ecology from both theoretical and empirical perspectives (Zhang *et al.* 2012). The recorded Shannon diversity values for trees in the present study ranged between 1.2–1.9 which is slightly higher than the temperate forests of western Himalaya. Further tree diversity decreased with increasing elevations, which was in accordance to the reported studies in the western Himalaya (Sharma *et al.* 2009; Singh & Kaushal 2006). Similarly, the species richness decreased with increase in elevation, which is in agreement with earlier studies (Bachman *et al.* 2004; Jacquemyn *et al.* 2005; Trigas *et al.* 2013). Overall the surveyed subalpine forest of Sikkim Himalaya possess good regeneration status seedling (3039 individual ha^{-1}) > sapling (1601 individual ha^{-1}) > tree (1504 individual ha^{-1}). Among the tree species, most of the *Rhododendron* spp. followed similar trend. Interestingly, the presence of *R. hodgsonii* seedlings in the higher elevations indicate the tolerance capacity of the species to the harsh climatic conditions of the higher elevation and in near future this species has the possibility to establish itself to comparatively higher elevations. However, further attention is required to develop a holistic understanding of ecosystem functioning across this highly diverse area.

Conclusion

The present study analyses vegetation structure along an elevation gradient of 3000–4000 m in subalpine forest zone up to timberline of Sikkim East Himalaya. The overall species richness and total basal area declined monotonically with elevation. The amplitude (range) of tree species varied across the gradient. The area possesses three layers of trees, i) understory layer of low DBH trees, ii) canopy layer of *Betula* spp.,*Vitex quinata, Rhododendron* spp., and iii) emergent layer of *Abies densa* and *Tsuga dumosa*. The lower elevation contributed the most in the total basal area (TBA). The tree species richness and diversity significantly decreased towards the higher elevation. The forest vegetation has species combinations of two contrasting sizes and densities of trees: large trees of conifers, particularly *A. densa* and small trees in very high densities of Ericaceae family, particularly *Rhododendron* spp. These two groups combine to give high tree basal area up to 3900 m. However, absence of conifers and low species richness of trees at the diffused timberline of the region correlated to lower basal area at the highest elevation site 4000 m. Under the current climate change scenario, this understanding of species distribution along the elevational gradient across remotely located subalpine forests will be helpful for planning management and conservation of biodiversity in the Himalayas.

Acknowledgements

This paper is a part of the “Timberline and Altitudinal Gradient Ecology of Himalayas, and Human Use Sustenance in a Warming Climate” (IHTP) project funded by the Ministry of Environment Forests and Climate Change, Government of India through National Mission on Himalayan Studies (NMHS), co-ordinate by Central Himalayan Environmental Studies (CHEA), Nainital. We thank the Department of Forests, Environment and Wildlife Management and Department of Home, Government of Sikkim for permission to carry out research work in protected areas. We thank Director G.B. Pant National Institute of Himalayan Environment and Sustainable Development (GBPNIHESD), Almora for providing necessary facilities to carry out the research work. The support of Mr. Bhim Pandey during field survey is duly acknowledged.

References

Acharya, B. K., B. Chettri & L. Vijayan. 2011. Distribution pattern of trees along an elevation gradient of Eastern Himalaya, India. *Acta Oecologica* **37**: 329–336.

Bachman, S., W. J. Baker, N. Brummitt, J. Dransfield & J. Moat. 2004. Elevational gradients, area and tropical island diversity: an example from the palms of New Guinea. *Ecography* **27**: 299–310.

Begon, M., C. R. Townsend & J. L. Harper. 2006. *Ecology: From Individuals to Ecosystems*. Blackwell Scientific Publications, UK.

Behera, M. D. & S. P. S. Kushwaha. 2007. An analysis of altitudinal behavior of tree species in Subansiri district, Eastern Himalaya. *Biodiversity Conservation* **16**: 1851–1865.

Bhattarai, K. R. & O. R. Vetaas. 2006. Can Rapoport's rule explain tree species richness along the Himalayan elevation gradient, Nepal? *Diversity and Distributions* **12**: 373–378.

Bhattarai, K. R., O. R. Vetaas & J. A. Grytnes. 2004. Fern species richness along a central Himalayan elevational gradient, Nepal. *Journal of Biogeography* **31**: 389–400.

Cardelus, C. L., R. K. Colwell & J. E. Watkins. 2006. Vascular epiphyte distribution patterns: explaining the mid elevation richness peak. *Journal of Ecology* **94**: 144–156.

Carpenter, C. 2005. The environmental control of plant species density on a Himalayan elevation gradient. *Journal of Biogeography* **32**: 999–1018.

Christensen, J. H., B. Hewitson, A. Busuioc, A. Chen, X. Gao, *et al.* 2007. Regional Climate Projections. *In*: S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor & H. L. Miller (eds.) *Climate Change 2007: The Physical Science Basis*. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press. Cambridge, United Kingdom.

Cullen, R. M. & S. J. Marshall. 2011. Mesoscale temperature patterns in the Rocky Mountains and foothills region of Southern Alberta. *Atmosphere-Ocean* **49**: 189–205.

Devi, N., F. Hagedorn, P. Moiseev, H. Bugmann, S. Shiyatov, V. Mazepa & A. Rigling. 2008. Expanding forests and changing growth forms of Siberian larch at the Polar Urals treeline during the 20th century. *Global Change Biology* **14**: 1581–1591.

Dhar, U. 2000. Prioritization of conservation sites in the timberline zone of west Himalaya in setting biodiversity conservation priorities for India. pp. 193–211. *In*: S. Singh, A. R. K. Sastry, R. Mehta & V. Uppal (eds.) *Setting Biodiversity Conservation Priorities for India*. WWF India.

Forrest, J. L., E. Wikramanayake, R. Shrestha, G. Areendran, K. Gyeltshen, A. Maheshwari, S. Mazumdar, R. Naidoo, G. J. Thapa & K. Thapa. 2012. Conservation and climate change: Assessing the vulnerability of snow leopard habitat to treeline shift in the Himalaya. *Biological Conservation* **150**: 129–135.

Gaire, N. P., M. Koirala, D. R. Bhuju & H. P. Borgaonkar. 2014. Treeline dynamics with climate change at the central Nepal Himalaya. *Climate of the Past* **10**: 1277–1290.

Gairola, S., R. S. Rawal & N. P. Todaria. 2015. Effect of anthropogenic disturbance on vegetation characterristics of sub-alpine forests in and around Valley of Flowers National Park, a world heritage site of India. *Tropical Ecology* **56**: 357–365.

Gairola, S., R. S. Rawal, N. P. Todaria & A. Bhatt. 2014. Population structure and regeneration patterns of tree species in climate-sensitive subalpine forests of Indian western Himalaya. *Journal of Forestry Research* **25**: 343–349.

Gaston, K. J. 1996. Species-range-size distributions: patterns, mechanisms and implications. *Trends in Ecology and Evolution* **11**: 197–201.

Graham, G. L. 1990. Bats Versus Birds: Comparisons among Peruvian volant vertebrate faunas along an elevational gradient. *Journal of Biogeography* **17**: 657–668.

Grau, O., J. A. Grytnes & H. J. B. Birks. 2007. A comparison of altitudinal species richness patterns of bryophytes with other plant groups in Nepal, Central Himalaya. *Journal of Biogeography* **34**: 1907–1915.

Hijmans, R. J., S. E. Cameron, J. L. Parra, P. G. Jones & A. Jarvis. 2005. Very high resolution interpolated climate surfaces for global land areas. *International Journal of Climatology* **25**: 1965–1978.

Jacquemyn, H., C. Micheneau, D. L. Roberts & T. Pailler. 2005. Elevational gradients of species diversity, breeding system and floral traits of orchid species on Réunion Island. *Journal of Biogeography* **32**: 1751–1761.

Jetz, W. & C. Rahbek. 2002. Geographic range size and determinants of avian species richness. *Science* **297**: 1548–1551.

Joshi, H. C. & S. S. Samant. 2004. Assessment of forest vegetation and conservation priorities of communities in part of Nanda Devi Biosphere Reserve, West Himalaya. Part I. *The International Journal of Sustainable Development & World Ecology* **11**: 326–336.

Kumar, A., B. G. Marcot & A. Saxena. 2006. Tree species diversity and distribution patterns in tropical forests of Garo Hills. *Current Science* **91**: 1370–1381.

Macias-Fauria, M. & E. A. Johnson. 2013. Warming-induced upslope advance of subalpine forest is severely limited by geomorphic processes. *Proceedings of the National Academy of Sciences* USA **110**: 8117–8122.

Magurran, A. E. 1988. *Ecological Diversity and its Measurement*. Springer, Dordrecht.

Misra, R. 1968. *Ecology Work Book*. Oxford and IBH Publishing Co., Calcutta, India.

Mueller-Dombois, D. & H. Ellenberg. 1974. *Aims and Methods of Vegetation Ecology*. John Wiley & Sons, Inc.

Olson, D. M. & E. Dinerstein. 2002. The Global 200: Priority ecoregions for global conservation. *Annals of the Missouri Botanical Garden* **89**: 199–224.

Olson, D. M., E. Dinerstein, E. D. Wikramanayake, N. D. Burgess, G. V. Powell, *et al*. 2001. Terrestrial ecoregions of the world: A new map of life on Earth. *BioScience* **51**: 933–938.

Oommen, M. A. & K. Shanker. 2005. Elevational species richness patterns emerge from multiple local mechanisms in Himalayan woody plants. *Ecology* **86**: 3039–3047.

Panigrahy, S., D. Anitha, M. M. Kimothi & S. P. Singh. 2010. Timberline change detection using topographic map and satellite imagery. *Tropical Ecology* **51**: 87–91.

Parthasarathy, N. 2001. Changes in forest composition and structure in three sites of tropical evergreen forest around Sengaltheri, Western Ghats. *Current Science* **80**: 389–393.

Pauli, H., M. Gottfried, S. Dullinger, O. Abdaladze, M. Akhalkatsi, J. L. B. Alonso, G. Coldea, J. Dick, B. Erschbamer, R. F. Calzado & D. Ghosn. 2012. Recent plant diversity changes on Europe's mountain summits. *Science* **336**: 353–355.

Peel, M. C., B. L. Finlayson & T. A. McMahon. 2007. Updated world map of the Köppen- Geiger climate classification. *Hydrology and Earth System Sciences* **11**: 1633–1644.

Phillips, E. A. 1959. *Methods of Vegetation Study*. Henry Holt & Co., New York.

Randin, C. F., R. Engler, S. Normand, M. Zappa, N. E. Zimmermann, *et al*. 2009. Climate change and plant distribution: local models predict high-elevation persistence. *Global Change Biology* **15**: 1557–1569.

Rawal, R. S. & U. Dhar. 1997. Sensitivity of timberline flora in Kumaun Himalaya, India: conservation implications. *Arctic and Alpine Research* **29**: 112–121.

Root, T. L., J. T. Price, K. R. Hall, S. H. Schneider, C. Rosenzweig & J. A. Pounds. 2003. Fingerprints of global warming on wild animals and plants. *Nature* **421**: 57.

Saikia, P., J. Deka, S. Bharali, A. Kumar, O. P. Tripathi, L. B. Singha, S. Dayanandan & M. L. Khan. 2017. Plant diversity patterns and conservation status of eastern Himalayan forests in Arunachal Pradesh, Northeast India. *Forest Ecosystems* **4**: 28.

Sharma, C. M., A. K. Mishra, O. Prakash, S. Dimri & P. Baluni. 2014. Assessment of forest structure and woody plant regeneration on ridge tops at upper Bhagirathi basin in Garhwal Himalaya. *Tropical Plant Research* **1**: 62–71.

Sharma, C. M., S. Suyal, S. Gairola & S. K. Ghildiyal. 2009. Species richness and diversity along an altitudinal gradient in moist temperate forest of Garhwal Himalaya. *Journal of American Science* **5**: 119–128.

Sharma, C. M., S. Suyal, S. K. Ghildiyal & S. Gairola. 2010. Role of physiographic factors in distribution of *Abies pindrow* (Silver Fir) along an altitudinal gradient in Himalayan temperate Forests. *The Environmentalist* **30**: 76–84.

Sharma, C. M., A. K. Mishra, O. P. Tiwari, R. Krishan & Y. S. Rana. 2017. Effect of altitudinal gradients on forest structure and composition on ridge tops in Garhwal Himalaya. *Energy, Ecology and Environment* **2**: 404–417.

Shrestha, U. B., S. Gautam & K. S. Bawa. 2012. Widespread Climate Change in the Himalayas and Associated Changes in Local Ecosystems. *PLoS One* **7**: e36741.

Singh, Y. & A. Kaushal. 2006. Extraction of geomorphological features using Radarsat 318 Data. *Journal of the Indian Society of Remote Sensing* **34**: 300–307.

Swamy, P. S., S. M. Sundarapandian, P. Chandrasekar & S. Chandrasekaran. 2000. Plant species diversity and tree population structure of a humid tropical forest in Tamil Nadu, India. *Biodiversity Conservation* **9**: 1643–1669.

Trigas, P., M. Panitsa & S. Tsiftsis. 2013. Elevational gradient of vascular plant species richness and endemism in Crete – the effect of post-isolation mountain uplift on a continental island system. *PLoS One* **8**: 59425.

Tse-ring, K., E. Sharma, N. Chettri, & A. B. Shrestha. 2010. *Climate Change Vulnerability of Mountain Ecosystems in the Eastern Himalayas*. International centre for integrated mountain development (ICIMOD), Kathmandu, Nepal.

Vetaas, O. R. & J. A. Grytnes. 2002. Distribution of vascular plant species richness and endemic richness along the Himalayan elevation gradient in Nepal. *Global Ecology and Biogeography* **11**: 291–301.

Vittoz, P., B. Rulence, T. Largey & F. Freléchoux. 2008. Effects of climate and land-use change on the establishment and growth of cembran pine (*Pinus cembra* L.) over the altitudinal treeline ecotone in the Central Swiss Alps. *Arctic, Antarctic, and Alpine Research* **40**: 225–232.

Walther, G. R., E. Post, P. Convey, A. Menzel, C. Parmesan, T. J. Beebee, J. M. Fromentin, O. Hoegh-Guldberg & F. Bairlein. 2002. Ecological responses to recent climate change. *Nature* **416**: 389.

Zhang, H., R. John, Z. Peng, J. Yuan, C. Chu, G. Du & S. Zhou. 2012. The relationship between species richness and evenness in plant communities along a successional gradient: a study from sub-alpine meadows of the Eastern Qinghai-Tibetan Plateau, China. *PloS One* **7**: 49024.

(Received on 23.06.2018 and accepted after revisions, on 24.07.2018)

Supporting Information

Additional Supporting information may be found in the online version of this article.

Table S1. Status of tree species along the subalpine conifer forest in Khangchendzonga National Park.

Table S2. Status of shrub species along the subalpine conifer forest in Khangchendzonga National Park.

Table S3. Status of herb species along the subalpine conifer forest in Khangchendzonga National Park.