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Effect of altitudinal gradients on forest structure and composition on ridge tops in Garhwal Himalaya

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Abstract Ridge top ecosystems (RTEs) are considered to be more sensitive to global warming as they are characterized by uniform sunlight exposure and low human interferences and hence are perfect places for monitoring and comparing the effects of climate change in species composition. The present study was carried out on RTEs of four different mountain ranges, viz. (1) Narendranagar–Hindolakhal (2) Mussoorie–Dhanolti (3) Chaurangikhal–Harunta and (4) Dayara–Gidara, along altitudinal gradient (situated below 2000 to above 3500 m), in Garhwal Himalaya to understand the variation in tree composition and distribution range. 0.1 ha-sized sample plot was used to analyze the tree species, whereas 5 m × 5 m for saplings and 1 m × 1 m for seedlings. The tree layers on RTEs were consisted of total 69 tree species, belonging to 55 genera and 39 families. *Shorea robusta*, *Pinus roxburghii*, *Rhododendron arboreum*, *Quercus leucotrichophora*, *Q. floribunda*, *Q. semecarpifolia*, *Cedrus deodara*, *Pinus wallichiana* and *Abies spectabilis* were found as the dominant and well-occupied tree species on the RTEs from lower to higher elevations. The mean stand density was recorded as 597 ± 29 trees ha^{-1} (ranged between 546 and 616 trees ha^{-1}) with a mean basal cover of 77.25 ± 17.90 m^2 ha^{-1} (ranged between 54.43 and 102.83 m^2 ha^{-1}). A traditional pattern for tree diversity was recorded which decreased with increasing altitude. The detrended correspondence analysis ordination plot clumped the species together which shared the same habitat and environmental conditions which revealed that elevation and geographic location were the dominant factors for regional differences in species composition among RTEs.

Keywords Climate change · Ecological indicators · Forest composition · Ridge top ecosystems · Detrended correspondence analysis

1 Introduction

The ridge top ecosystems (RTEs) are considered to be more sensitive to global warming as they are characterized by uniform sunlight exposure and low human interferences and hence are perfect places for monitoring and comparing the effects of climate change and predicting the future changes in species composition. In Himalayan region, elevation and climatic factors are the governing factors for regional differences in species composition (Lee and Chun 2016; Sharma et al. 2016). Furthermore, it is supposed that in the event of a rise in temperature at lower elevations the movement/migration of vegetation would be toward upper elevational (Chen and Hill 2011). The recent global warming has resulted in disturbances of ecological relationships, alteration in plant life history and general upward shift in the species distributional ranges (Jurasinski and Kreyling 2007; Pauli et al. 2012). Climate controls the distribution of vegetation (Sharma et al. 2016), and thus, future changes in climate are projected to cause changes in the vegetation distribution ranges. Several studies have attributed widespread changes in plant growth or mortality to climate change, but these efforts have focused on general trends within a biome rather than identifying spatially

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coherent distribution pattern (Pauli et al. 2007; Engler et al. 2009).

The composition and ecosystem services of Himalayan forests depend on forest structure, which is believed to be changing over time. Gottfried et al. (2012) reported ample evidences that ongoing climate change continuously affects the Himalayan Vegetation along with its different components. Rapid geo-climatic variations at different altitudes in Himalaya generate diverse vegetation structure and high species diversity (Chawla et al. 2008). Intensity of major threats to forest ecosystems and biodiversity along altitudinal gradient is directly measured by compositional changes in forest structure. Role of habitat loss due to fragmentation, overexploitation, invasion by alien species and global climate change is premier in disruption of community structure along the altitudinal gradient, which can be used to assess the status of forest composition and alert for future changes. Lots of work have been done on the effects of elevational gradients on forest structure and composition (Sharma et al. 2010; Gairola et al. 2012; Rawat and Chandra 2014), but the studies on change in species composition on RTEs along the altitudinal gradient in Himalaya are completely lacking.

In the western Himalayan region, along lowest and highest elevational transects the changes in forest composition are evident, but they are required to be measured properly (Chitale et al. 2014; Sharma et al. 2014). Projecting future changes in species composition and distribution of vegetation on RTEs at different altitudes is a crucial step toward planning and mitigating the impacts of climate change on biodiversity. The aim of the study is to describe and analyze the forest structure, composition and distribution pattern along elevational gradients, in order to explain the changes in forest composition and characters of forests on RTEs in response to changing climate.

2 Methodology

2.1 Study area

The study was conducted in four different mountain ranges, viz. (1) Narendranagar–Hindolakhal (<2000 m) (2) Mussoorie–Dhanolti (1900–2900 m) (3) Chaurangikhal–Harunta (2400–3300 m) and (4) Dayara–Gidara (2500–3750 m), of Garhwal Himalaya to assess tree species composition and distribution on different RTEs along the elevational gradient (Above sea level). For this purpose, we selected the RTEs from lower to higher elevations in aforesaid different mountain ranges. In these ranges, the selected RTEs were studied on five different elevations, viz. (a) <2000 m (b) 2000–2500 m (c) 2500–3000 m (d) 3000–3500 and (e) >3500 m. The study areas were situated in the catchment of river Ganges (called Bhagirathi toward upstream). Details of study area, forest types and dominant tree species within the selected elevations are shown in Table 1 and Fig. 1.

All the mountain ranges were characterized by undulating topography with gentle slopes on northern, northeastern and northwestern faces and somewhat steep slopes on southern and southwestern directions. Ridges are continuous elevated top made by chain of mountains (Fig. 2). Numerous high ridges, deep gorges and precipitous cliffs, rocky crates and narrow valleys were part of the topography in all the ranges. Geologically, the rocks were complex mixture of mainly sedimentary, low-grade metamorphosed rocks with sequences capped by crystalline nappe (Valdiya 1980).

2.2 Vegetation composition

The patterns of forest structure over RTEs were assessed along the elevational gradient in the selected four mountain ranges. The results of all the ranges were compared with one another. Various RTEs along with several plant communities provided an excellent base to investigate the climatic control on plant distribution. The sample plots were laid out from lower to higher elevations, climbing through subtropical, temperate to subalpine forests.

The forest composition was analyzed by laying out a total of 30 sample plots of 0.1 ha each, and three vegetation layers (trees, saplings and seedlings) were studied for knowing the species richness, density, diversity and regeneration status of various forest-forming species as per (Kent and Coker 1992). The trees ($\geq$10 cm dbh) were analyzed by 0.1 ha-sized sample plots, whereas saplings by ten 5 m $\times$ 5 m-sized quadrats and seedling by five 1 m $\times$ 1 m-sized quadrats, which were randomly laid out within a 0.1 ha sample plots on each site. Circumference at breast height (cbh = 1.37 m) was taken for the determination of tree basal area, and in case of saplings and seedlings, it was taken at collar height and finally was calculated as πr^2 (where r is the radius). The data were quantitatively analyzed for density, frequency and abundance, following Curtis and McIntosh (1950). Density and total basal cover values were converted to per hectare (ha^{-1}) for extrapolation of the results. Basal cover (m^2 ha^{-1}) was used to determine the relative dominance of a tree species. Importance value index (IVI) was the sum of relative frequency, relative density and relative dominance (Phillips 1959) of a species. Shannon–Weaver index ($\bar{H}$) (Cootam and Curtis 1956), Simpson's dominance index (C) (Simpson 1949) and Hill diversity numbers N0, N1 and N2 (Hill 1973) were computed. With the help of CANOCO 5 and SPSS-20 softwares, the results were correlated with temperature, elevation and local climatic conditions to predict the future changes in the vegetation at RTEs.

Table 1 List of dominant woody plant species in different life phase at different altitudes

Altitude	Studied area	Dominant forest type	Dominant tree species
<2000	Hindolakhal, Mussoorie, Chaurangikhal	Tropical moist	*S. robusta, Q. leucotrichophora, T. chebula*
2000–2500	Mussoorie, Dayara–Gidara, Chaurangikhal	Moist temperate	*R. arboretum, Q. floribunda, Q. leucotrichophora*
2500–3000	Mussoorie, Dayara–Gidara, Chaurangikhal	Moist temperate	*Q. floribunda, Q. semecarpifolia, A. pindrow*
3000–3500	Dayara–Gidara, Chaurangikhal	Moist temperate	*A. spectabilis, Q. semecarpifolia, B. utilis*
>3500	Dayara–Gidara	Subalpine	*Q. semecarpifolia, A. spectabilis, B utilis*
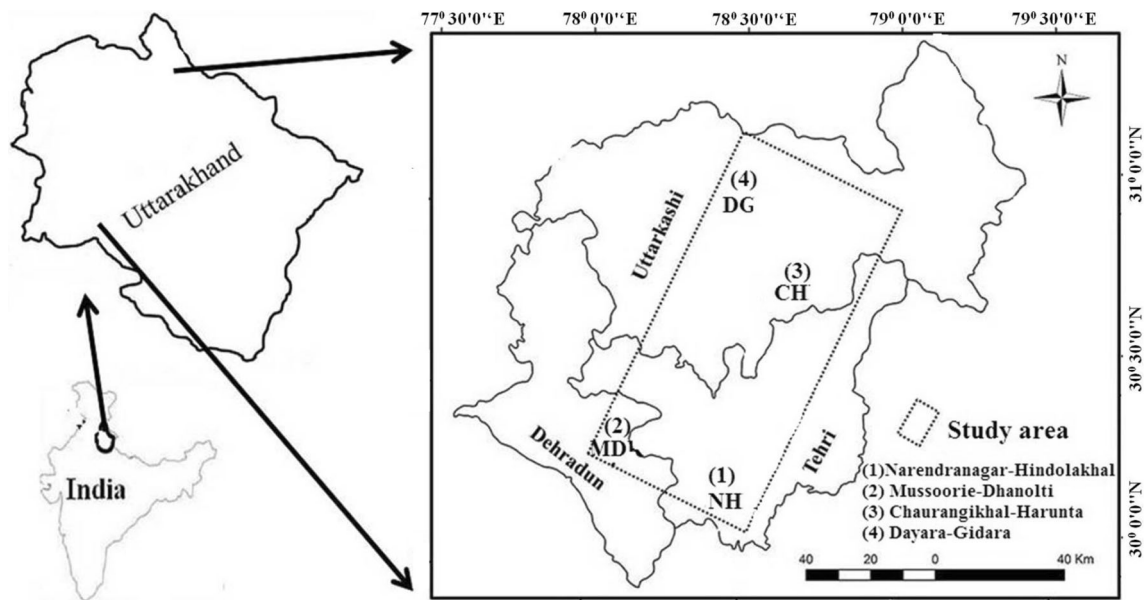
Fig. 1 Map representing the study area

3 Results

3.1 Altitudinal variation in species composition

The structure and composition of the tree species on various RTEs and elevations are presented in Table 1. *Shorea robusta, Pinus roxburghii, Rhododendron arboreum, Cedrus deodara, Quercus semecarpifolia, Q. floribunda, Q. leucotrichophora, Pinus wallichiana* and *Abies spectabilis* were the dominant tree species on RTEs at various elevations (Table 2). The tree layers on all RTEs were consisted of 69 species, represented by 55 genera and 39 families in the study area. Pinaceae and Fabaceae were the dominant families represented by 6 tree species each. Mean stand (stem) density was observed as 597 ± 29 trees ha^{-1}, which ranged between 546 and 616 trees ha^{-1} with a total basal cover (TBC) of 77.25 ± 17.90 m^2 ha^{-1} (ranging from 54.43 to 102.83 m^2 ha^{-1}) on various ridge top forests. Biodiversity index showed lowest Simpson index value (0.07) on <2000 m and highest (0.44) on >3500 m.

The RTEs of lower altitudes (<2000 m.) were highly diverse as compared to other altitudes and therefore showed highest value (1.3). The details of forest composition in terms of species frequency, density, basal cover and importance value index on different ridge top forests of all five altitudinal ranges are given in Table 2.

3.2 DBH Class distribution

Overall diameter class density, species richness and basal cover distribution on different elevational ranges represented different patterns, i.e., reverse J-shaped, interrupted J-shaped and bell-shaped. Based on the overall basal cover distribution, on RTEs above 3500 m elevation, an established forest was recorded (this may be because of least disturbance in the inaccessible areas), followed by 3000–3500 m elevation range, where mature forests were prevalent; however, on RTEs situated below 2000 m elevation, younger regenerating forests were recorded (probably because of their situation near

Fig. 2 Ridge tops of study area

Table 2 Tree species composition along the different elevational ranges

Altitude	<2000	2000–2500	2500–3000	3000–3500	>3500
Species richness	46	20	24	13	3
Genus	40	18	19	12	3
Family	27	12	14	8	3
Stem density (ha^{-1})	546	615	600	616	610
Total basal cover (m^2 ha^{-1})	54.43	70.11	74.62	84.25	102.83
Simpson index	0.07	0.12	0.13	0.20	0.44
Shannon–Wiener index	1.29	1.05	1.01	0.81	0.39
Species evenness	0.78	0.81	0.73	0.73	0.82
Hill diversity					
H_0	46	20	24	13	3
H_1	1.07	1.13	1.14	1.22	1.55
H_2	0.77	0.95	0.99	1.24	2.54

habitation zone). The tree density and species richness under different size classes showed a reverse J-shaped pattern in all five altitudinal ranges, whereas above 3500 m elevational range dbh density pattern was bell-shaped (normal distribution). The dbh class-based basal cover data also followed the bell-shaped curve at highest altitude (Fig. 3a, b, c).

3.3 Species composition and distribution pattern along the elevational gradients

Detrended correspondence analysis clearly showed that vegetation distribution and association with the RTEs of various mountain ranges were highly similar to each other (Fig. 4). Among five different elevational ranges, the
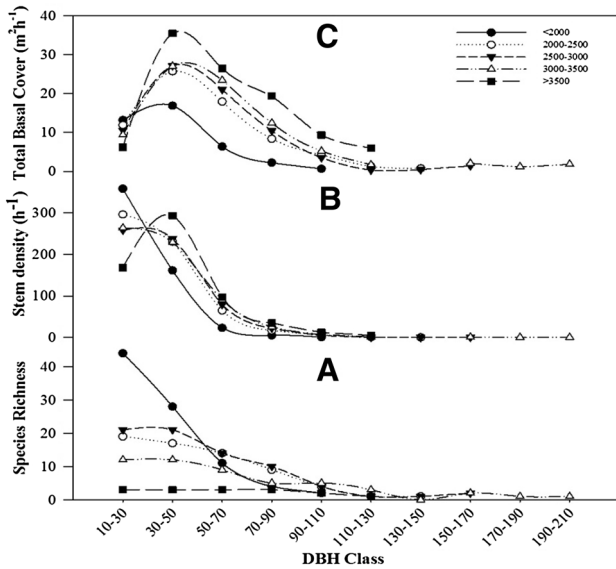
Fig. 3 Forest composition by DBH classes (cm) at different altitudes (m); **a** species richness, **b** stem density and **c** total basal cover (m^2 ha^{-1})

distribution of vegetation was recorded on four different axes which represented four major groups. Forest distribution on <2000 m RTE was highly dissimilar to other altitudes. DCA diagram has shown that vegetation structure between 2500 and 3500 m was almost similar (Fig. 4). The frequency distribution pattern of 34 species is given in Fig. 5. Order of widely distributed species among all ranges was *C. deodara* (1450–3252 m) **>** *R. arboreum* (1732–3474 m) > *L. ovalifolia* (1732–3474 m) > *Q. semecarpifolia* (2320–3540 m) > *P. wallichiana* (2072–3252 m) > *Q. leucotrichophora* (428–2592 m) > *P. smithiana* (2072–3125) etc. Linear regression analysis between the components of forest composition and elevational gradients is also shown in Fig. 6.

4 Discussion

Plant species may respond to global warming either by adapting their life cycles to the new conditions or by migrating upwards from their conventional distribution

Fig. 4 Detrended correspondence analysis to assess species composition and similarity in vegetation along different altitudes
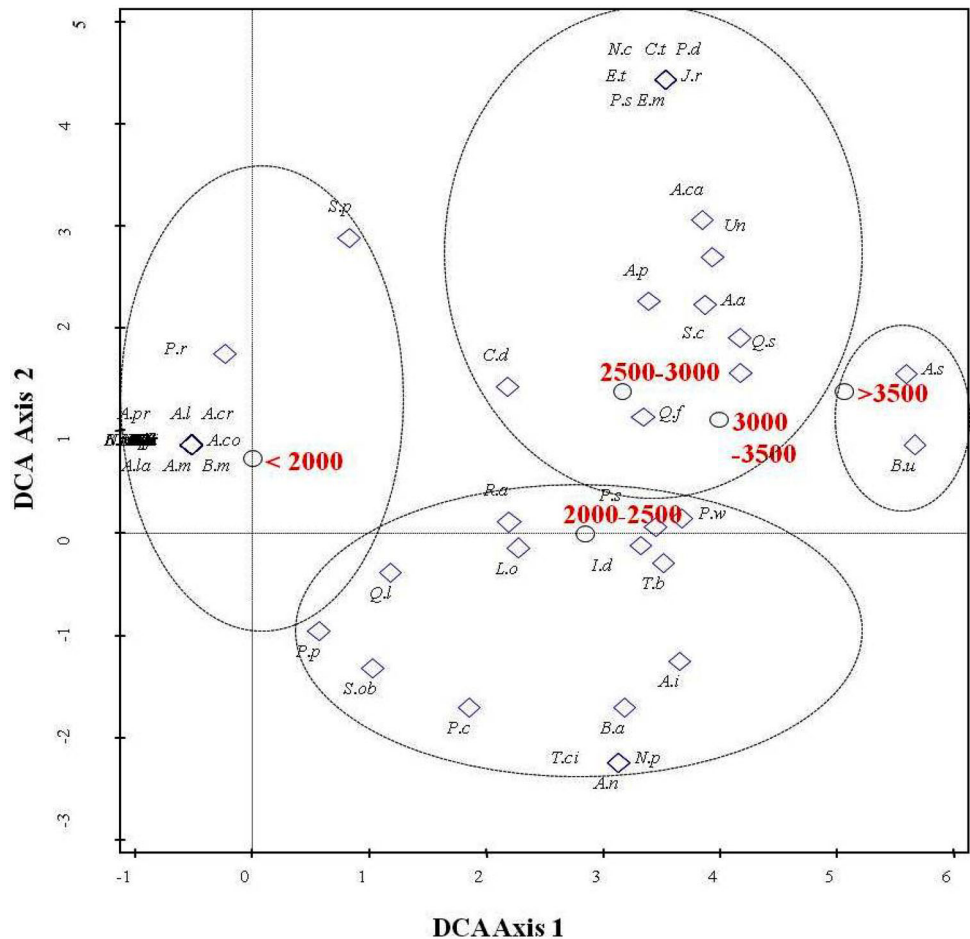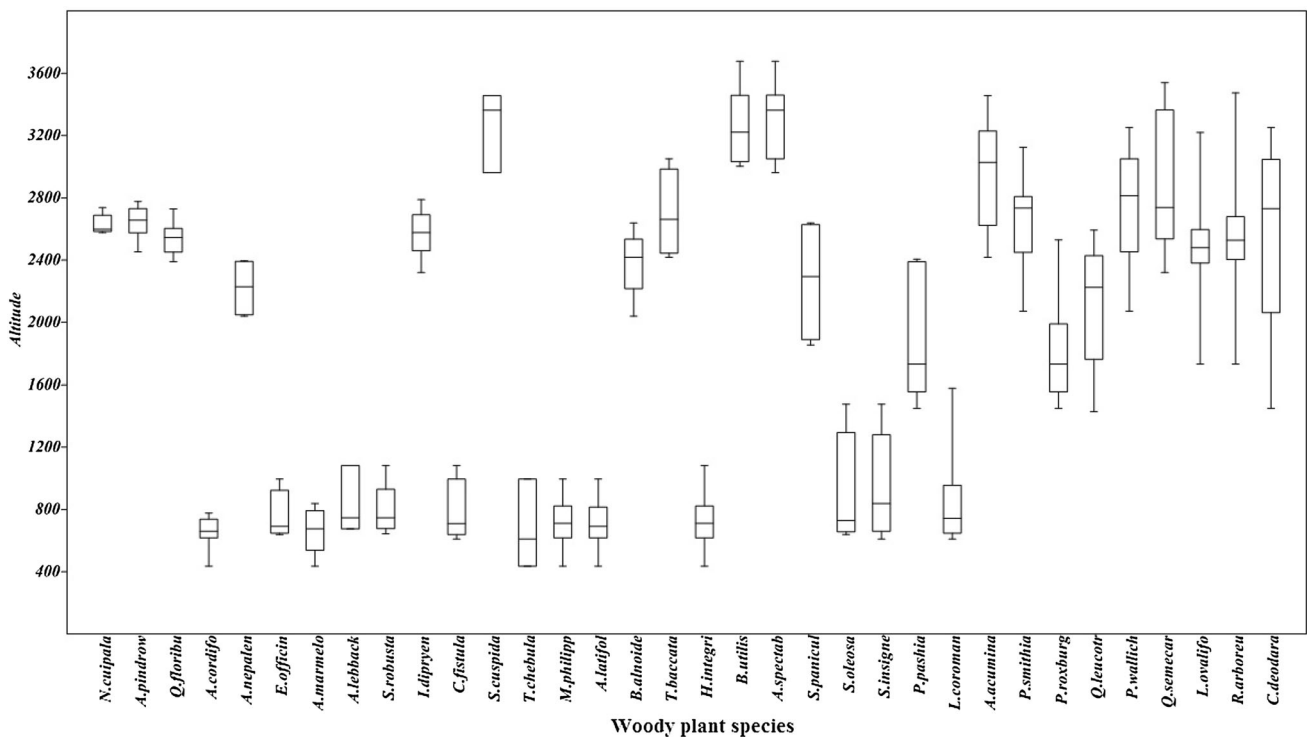
Fig. 5 Distributional range of dominant woody plant species along the altitudes

ranges to more suitable habitats (Bellard et al. 2012). The study revealed that tree species found in this part of Himalaya exhibited a pattern of distribution along different altitudinal and climatic gradients (Subedi et al. 2015). Tree species richness was observed to be highest (47 species) below 2000 m elevational zone, followed by 2500–3000 m (26) and 3000–3500 m (20) and lowest (3 species) above 3500 m. More than two-third of plant species were encountered at the elevation range below 2000 m, where the temperature range was found fluctuating between 8 and 37 °C. Similar results of species richness were reported by Burns (1995) and Austin et al. (1996) in their elevational gradients study. The total species richness was greatest at lower elevation (warmer sites) as compared to the higher elevation (cooler sites).

Assessment of biodiversity and their drivers along environmental gradients is one of the central topics in ecology (Lee and Chun 2016). The variation in quantitative parameters, species richness as well as forest composition among all studied RTEs may be due to difference in climatic, physiographic and edaphic factors. Distributional ranges of several species were reported as segregated along the widened elevational ranges (Kharkwal et al. 2005). Pauses and Austin (2001) suggested that over any large area, the distribution of species richness is likely to be governed by two or more environmental factors. Trends of species richness on RTEs of this study were almost similar to other elevational gradient studies, because the decline in

species richness with increasing elevation is widely accepted (Rahbek 1995; Sharma et al. 2016).

The mean stand density on various RTEs was recorded as 597 ± 29 stems ha^{-1} (which ranged between 546 and 616 stems ha^{-1}) and mean value of TBC as 77.25 ± 17.9 m^2 ha^{-1} (which ranged from 54.4 to 102.83 m^2 ha^{-1}). However, there was a gradual increase in density with an increase in elevation, which is in conformity with the studies performed in the Western Ghats by Parthasarathy and Karthikeyan (1997) and in Himalayan temperate forests by Samant et al. (2002). The recorded density values of this study did not vary considerably from values reported by other authors (Adhikari and Tiwari 1991; Singhal and Soni 1989; Ilorkar and Khatri 2003). From Garhwal Himalaya, Pande (2001) had reported a stem density of 792–1111 stems ha^{-1}, which is higher than our values, whereas the reported TBC range (56–126 m^2 ha^{-1}) was similar to our study. All the results on vegetation composition were in accordance with the earlier reported findings by various ecologists for moist Himalayan temperate forests (Singh and Kaushal 2006; Sharma et al. 2009, 2014, 2015).

Forest dominance increased with an increase in the elevation. Simpson's index value was 0.07 below 2000 m, which gradually increased and reached finally up to 0.44 for the forest vegetation above 3500 m. This was due to tolerance-based dominance of only few tree species under severe environmental conditions. Shannon–Weiner's index values ranged from 0.39 to 1.3 and decreased with
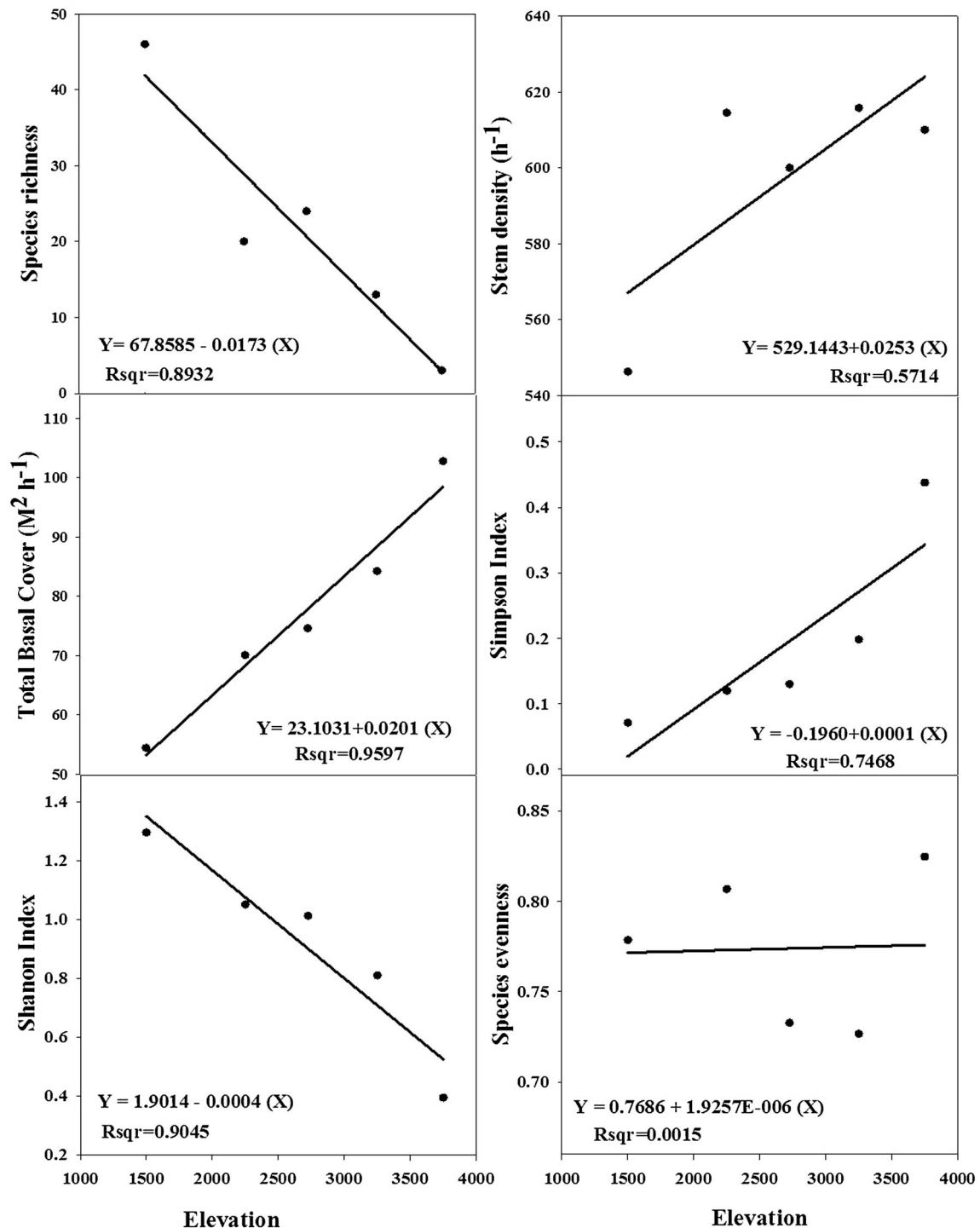
Fig. 6 Linear regression analysis between forest composition and elevation

increasing altitudes/elevations, which was in accordance with the values reported for other temperate forests (Singh and Kaushal 2006; Sharma et al. 2009). The high importance value index (IVI) of species between 600 and 1100 m indicated their dominance and ecological success, good

power of regeneration and ecological amplitude. Similar observations were also recorded by Singh et al. (1991), Gogate and Kumar (1993) and Ilorkar and Khatri (2003).

The DCA revealed that elevation and geographic location were the dominant factors underlying regional

Table 3 Tree vegetation structure on ridge tops at different elevational ranges

Tree species	Family	<2000				2000–2500				2500–3000			
		Fr	D	TBC	IVI	Fr	D	TBC	IVI	Fr	D	TBC	IVI
Abies pindrow (D. Don) Royle	Pinaceae					5	17.5	2.65	8.18	33.06	83.55	15.62	46.31
Abies spectabilis D. Don	Pinaceae									0.81	0.97	0.27	0.8
Acacia catechu (L. f.) Willd.	Fabaceae	8.33	5	0.33	4								
Acer acuminatum Wall. ex D. Don	Aceraceae					1.25	1	0.07	0.65	7.26	9.03	0.66	4.9
Acer caesium Wall. ex Brandis subsp. *caesium*	Aceraceae									1.61	0.97	0.11	0.87
Adina cordifolia (Roxb.) Hook. f. & Benth.	Rubiaceae	17.71	15.83	1.13	10.22								
Aegle marmelos (L.) Corrêa	Rutaceae	10.42	13.33	0.34	6.15								
Aesculus indica (Wall. ex Cambess.) Hook.	Sapindaceae					1.25	1.5	0.21	0.93				
Albizia lebbeck (L.) Benth.	Fabaceae	3.13	1.25	0.05	1.25								
Albizia procera (Roxb.) Benth.	Fabaceae	1.04	0.42	0.02	0.42								
Alnus nepalensis D. Don	Betulaceae					10	10.5	2.26	8.03				
Anogeissus latifolia (Roxb. ex DC.) Wall. ex Guill. & Perr.	Combretaceae	35.42	53.33	3.82	27.28								
Averrhoa carambola L.	Oxalidaceae	1.04	0.83	0.03	0.52								
Bauhinia malabarica Roxb.	Fabaceae	2.08	1.67	0.06	1.04								
Bauhinia variegata L.	Fabaceae	2.08	0.83	0.03	0.83								
Betula alnoides Buch.-Ham. ex D.Don	Betulaceae					13.8	17	1.69	9.42	0.81	0.32	0.04	0.38
Betula utilis D. Don	Betulaceae												
Boehmeria platyphylla Buch.-Ham. ex D. Don	Urticaceae	2.08	0.83	0.08	0.65								
Boehmeria rugulosa Wedd.	Urticaceae	1.04	0.83	0.1	9.07								
Cassia fistula L.	Caesalpiniaceae	19.79	13.33	0.42	17.95								
Cedrus deodara (Roxb. ex D. Don) G. Don	Pinaceae	11.46	36.25	4.31	0.71	10	22.5	2.81	10.75	9.68	44.52	5.02	17.5
Celtis australis L.	Ulmaceae	1.04	0.83	0.13	0.4								
Cocculus laurifolius DC.	Menispermaceae	1.04	0.42	0.01	1.7								
Cornus oblonga Wall.	Cornaceae	2.08	1.25	0.07	0.9	3.75	2	0.08	1.6				
Cupressus torulosa D. Don	Cupressaceae									0.81	0.32	0.01	0.34
Engelhardtia spicata Lechen ex Blume	Juglandaceae	4.17	5.42	0.17	0.74								
Euonymus tingens Wall.	Celastraceae									0.81	1.61	0.05	5.74
Ficus benghalensis L.	Moraceae	1.04	0.42	0.19	0.41								
Ficus hispida L. f. var. *odorata* Blanco	Moraceae	1.04	0.42	0.01	1.04								
Ficus rumphii Blume	Moraceae	2.08	1.25	0.11	1.44								
Hesperethusa crenulata (Roxb.) M. Roem.	Rutaceae	3.13	1.67	0.11	9.16								
Holoptelea integrifolia (Roxb.) Planch.	Ulmaceae	14.58	18.33	0.81	0.43								
Ilex dipyrena Wall. in Roxb.	Aquifoliaceae					15	12	0.96	7.96	12.1	7.1	0.28	1.65
Juglans regia L.	Juglandaceae									1.61	0.65	0.74	8.77

Table 3 continued

Tree species	Family	<2000				2000–2500				2500–3000			
		Fr	D	TBC	IVI	Fr	D	TBC	IVI	Fr	D	TBC	IVI
Lagerstroemia parviflora Roxb.	Lythraceae	1.04	0.42	0.03	10								
Lannea coromandelica (Houtt.) Merr.	Anacardiaceae	19.79	12.5	1.01	0.93								
Leucaena leucocephala (Lam.) de Wit	Fabaceae	1.04	2.08	0.13	7.37								
Lyonia ovalifolia (Wall.) Drude	Ericaceae	10.42	17.08	0.63	0.43	35	28.5	2.11	18.47	16.94	10.97	0.8	8.31
Madhuca latifolia (Roxb.) J. F. Macbr.	Sapotaceae	1.04	0.42	0.03	15.93								
Mallotus philippensis (Lam.) Müll. Arg.	Euphorbiaceae	22.92	36.67	1.32	0.89								
Miliusa tomentosa (Roxb.) Sinclair	Annoneaceae	2.08	1.25	0.02	0.54								
Miliusa velutina (Dunal.) Hook. f. & Thoms.	Annoneaceae	1.04	0.42	0.11	20.12								
Neolitsea cuipala (Buch.-Ham. ex D. Don) Kosterm	Lauraceae									10.48	19.68	1.05	0.34
Neolitsea pallens (D. Don) Momiyama and Hara	Lauraceae					5	3.5	0.07	2.21				
Nyctanthes arbor-tristis L.	Oleaceae	1.04	0.83	0.04	0.4								
Persea duthiei	Lauraceae									0.81	0.32	0.01	12.99
Picea smithiana (Wall.) Boiss	Pinaceae					18.8	25	4.93	16.89	15.32	21.61	3.05	0.42
Pinus roxburghii Sarg.	Pinaceae	18.8	27.5	5.19	3.84					0.81	0.65	0.03	19.22
Pinus wallichiana A. B. Jacks.	Pinaceae					22.5	43.5	8.71	26.45	17.74	43.55	4.34	2.17
Phyllanthus emblica L.	Euphorbiaceae	4.17	1.67	0.09	2.54								
Populus ciliata Wall. ex Royle	Salicaceae									4.03	1.94	0.33	63.7
Prunus cornuta L.	Rosaceae	1.04	0.42	0.01	35.11	2.5	3	0.42	1.86				
Pyrus pyrifolia (Burm. f.) Nakai	Rosaceae	7.29	7.08	0.21	19.61	5	3	0.06	2.12				
Quercus floribunda Lindl. ex A. Camus	Fagaceae					45	175	10.97	58.03	50	160.97	14.59	6.51
Quercus leucotrichophora A. Camus	Fagaceae	22.92	80	7.44	5.74	32.5	64	8.8	33	4.03	15.48	1.89	51.88
Quercus semecarpifolia Sm.	Fagaceae					21.3	37.5	4.56	19.17	37.9	86.77	18.13	40.9
Rhododendron arboreum Sm.	Ericaceae	12.5	57.92	2.89	2.93	65	127	16.34	64.04	53.23	80.65	6.73	0.37
Sapium insigne (Royle) Trimen	Euphorbiaceae	12.5	8.33	0.28	37.52								
Schleichera oleosa (Lour.) Merr	Sapindaceae	6.25	4.17	0.17	0.97								
Shorea robusta Gaertn. f.	Dipterocarpaceae	25	101.67	6.26	0.79								
Sorbus cuspidata Hedl.	Rosaceae									0.81	0.32	0.03	0.72
Symplocos paniculata Miq.	Symplocaceae	2.08	0.83	0.01	32.43					1.61	0.65	0.04	4.58
Syzygium cumini (L.) Skeels	Martiaceae	2.08	0.83	0.07	1.93								
Taxus baccata L. var. *fastigiata* (Lindl.) Loudon	Taxaceae					10	20	2.39	9.75	6.45	7.42	0.83	0.61
Terminalia chebula Retz.	Combretaceae	7.29	5.83	15.9	0.43								
Terminalia elliptica Willd.	Combretaceae	4.17	2.08	0.17	0.58								
Toona ciliata M. Roem.	Meliaceae					1.25	0.5	0.02	0.49				
Ulmus wallichiana Planch.	Ulmaceae	1.04	0.42	0.03	0.92								

Table 3 continued

Tree species	Family	<2000				2000–2500				2500–3000			
		Fr	D	TBC	IVI	Fr	D	TBC	IVI	Fr	D	TBC	IVI
Ziziphus glaberrima Lam.	Rhamnaceae	4.17	2.08	0.08	1.76								
		338	546.25	54.43	300	324	614.5	70.11	300	288.71	600	74.62	300

Tree species	Family	3000–3500				>3500			
		Fr	D	TBC	IVI	Fr	D	TBC	IVI
Abies pindrow (D. Don) Royle	Pinaceae								
Abies spectabilis D. Don	Pinaceae	57.89	229.47	26.42	94.06	75	195	47.1	120.58
Acacia catechu (L. f.) Willd.	Fabaceae								
Acer acuminatum Wall. ex D. Don	Aceraceae	21.05	14.74	1.12	12.98				
Acer caesium Wall. ex Brandis subsp. caesium	Aceraceae	1.32	0.53	0.04	0.71				
Adina cordifolia (Roxb.) Hook. f. and Benth.	Rubiaceae								
Aegle marmelos (L.) Corrêa	Rutaceae								
Aesculus indica (Wall. ex Cambess.) Hook.	Sapindaceae	1.32	0.53	0.04	0.71				
Albizia lebbeck (L.) Benth.	Fabaceae								
Albizia procera (Roxb.) Benth.	Fabaceae								
Alnus nepalensis D. Don	Betulaceae								
Anogeissus latifolia (Roxb. ex DC.) Wall. ex Guill. & Perr.	Combretaceae								
Averrhoa carambola L.	Oxalidaceae								
Bauhinia malabarica Roxb.	Fabaceae								
Bauhinia variegata L.	Fabaceae								
Betula alnoides Buch.-Ham. ex D.Don	Betulaceae								
Betula utilis D. Don	Betulaceae	39.47	82.63	10.79	43.57	25	25	5.3	23.5
Boehmeria platyphylla Buch.-Ham. ex D. Don	Urticaceae								
Boehmeria rugulosa Wedd.	Urticaceae								
Cassia fistula L.	Caesalpiniaceae								
Cedrus deodara (Roxb. ex D. Don) G. Don	Pinaceae	13.16	18.42	7.9	18.14				
Celtis australis L.	Ulmaceae								
Cocculus laurifolius DC.	Menispermaceae								
Cornus oblonga Wall.	Cornaceae								
Cupressus torulosa D. Don	Cupressaceae								
Engelhardtia spicata Lechen ex Blume	Juglandaceae								
Euonymus tingens Wall.	Celastraceae								
Ficus benghalensis L.	Moraceae								
Ficus hispida L. f. var. odorata Blanco	Moraceae								

Table 3 continued

Tree species	Family	3000–3500				>3500			
		Fr	D	TBC	IVI	Fr	D	TBC	IVI
Ficus rumphii Blume	Moraceae								
Hesperethusa crenulata (Roxb.) M. Roem.	Rutaceae								
Holoptelea integrifolia (Roxb.) Planch.	Ulmaceae								
Ilex dipyrena Wall. in Roxb.	Aquifoliaceae								
Juglans regia L.	Juglandaceae								
Lagerstroemia parviflora Roxb.	Lythraceae								
Lannea coromandelica (Houtt.) Merr.	Anacardiaceae								
Leucaena leucocephala (Lam.) de Wit	Fabaceae								
Lyonia ovalifolia (Wall.) Drude	Ericaceae	5.26	11.05	1.32	5.68				
Madhuca latifolia (Roxb.) J. F. Macbr.	Sapotaceae								
Mallotus philippensis (Lam.) Müll. Arg.	Euphorbiaceae								
Miliusa tomentosa (Roxb.) Sinclair	Annoneaceae								
Miliusa velutina (Dunal.) Hook. f. and Thoms.	Annoneaceae								
Neolitsea cuipala (Buch.-Ham. ex D. Don) Kosterm	Lauraceae								
Neolitsea pallens (D. Don) Momiyama and Hara	Lauraceae								
Nyctanthes arbor-tristis L.	Oleaceae								
Persea duthiei	Lauraceae								
Picea smithiana (Wall.) Boiss	Pinaceae	1.32	2.63	0.05	1.07				
Pinus roxburghii Sarg.	Pinaceae								
Pinus wallichiana A. B. Jacks.	Pinaceae	30.26	87.37	10.44	39.88				
Phyllanthus emblica L.	Euphorbiaceae								
Populus ciliata Wall. ex Royle	Salicaceae								
Prunus cornuta L.	Rosaceae								
Pyrus pyrifolia (Burm. f.) Nakai	Rosaceae								
Quercus floribunda Lindl. ex A. Camus	Fagaceae								
Quercus leucotrichophora A. Camus	Fagaceae								
Quercus semecarpifolia Sm.	Fagaceae	36.84	152.63	24.41	69.94	75	390	50.5	155.92
Rhododendron arboreum Sm.	Ericaceae	7.89	8.42	1.1	6.14				
Sapium insigne(Royle) Trimen	Euphorbiaceae								
Schleichera oleosa (Lour.) Merr	Sapindaceae								
Shorea robusta Gaertn. f.	Dipterocarpaceae								
Sorbus cuspidata Hedl.	Rosaceae	7.89	5.79	0.59	5.11				
Symplocos paniculata Miq.	Symplocaceae								
Syzygium cumini (L.) Skeels	Martiaceae								

Table 3 continued

Tree species	Family	3000–3500				>3500			
		Fr	D	TBC	IVI	Fr	D	TBC	IVI
Taxus baccata L. var. *fastigiata* (Lindl.) Loudon	Taxaceae	3.95	1.58	0.02	2.02				
Terminalia chebula Retz.	Combretaceae								
Terminalia elliptica Willd.	Combretaceae								
Toona ciliata M. Roem.	Meliaceae								
Ulmus wallichiana Planch.	Ulmaceae								
Ziziphus glaberrima Lam.	Rhamnaceae								
		227.63	615.79	84.25	300	175	610	102.8	300

Fr Frequency, *D* density, *TBC* total basal cover, *IVI* importance value index

differences in the species composition among sites. DCA clearly showed that vegetation distribution and association with the RTEs of various mountain ranges were focused along the first two DCA axes. RTEs at higher elevations were highly similar in species composition, whereas the vegetation of lower elevation was dissimilar to higher elevation. Mountain topography can influence temperature differences over very short vertical distances (Scherrer and Körner 2010). Elevation itself represents a complex combination of related climatic variables closely correlated with numerous other environmental properties, i.e, soil texture, nutrients and substrate stability (Ramsay and Oxley 1997). Within one elevation, the cofactors such as topography, aspect, inclination of slope and soil types further affect the forest composition (Holland and Steyn 1975). Zhuang et al. (2012) and Moeslund et al. (2013) suggested that differential distribution of solar radiation might produce differences in microclimate (e.g., temperature) and water balance (moisture), which results in growth of different plant communities. Our DCA study shows that aforesaid factors may cause major differences in vegetation composition at different elevations, but these do not affect the higher elevational RTs where almost similar composition and diversity status were observed (Table 3).

Distributional pattern of species showed that at lower elevation, the dominance of subtropical *S. robusta* was affected by *Anogeissus latifolia,* whereas in temperate region, the *P. roxburghii* forests were found replacing the *Quercus* spp. (from broadleaf and mixed broadleaf forests) gradually. At the middle elevations, however, the coniferous species such as *C. deodara* and *Cupressus torulosa* were also predominantly replacing the broadleaf forests. In subalpine forests, birch (*Betula utilis*) and fir (*A. spectabilis*) forests along with some broadleaf species, viz. *R. arboreum, Q. semecarpifolia,* etc., have revealed the dominance. The *B. utilis, A. spectabilis* and *R. arboreum* were also found encroaching the lower alpine meadows through species migration (Sharma et al. 2014). Species distribution along altitudinal gradient was directly controlled by ecophysiological processes of temperature tolerance (Körner 2003). Species from warmer lower elevational vegetation belts took advantage of the improved growing conditions to extend their leading edges to the temperate and subalpine belts at the expense of cold-adapted species already occurring there. Linear regression was used to assess the effect of elevational gradient in the species composition on ridge tops. Species richness and tree species diversity were negatively correlated with elevational gradient and decreased with increasing elevation. The occurrence of higher diversity and species richness on lower elevational RTs might thus be explained by the invasion susceptibility of the communities with ample available gaps in sparse vegetation due to anthropogenic

disturbances, mainly structured by facilitative interactions (Choler et al. 2001). The homogeneous forest was recorded at higher altitudes which emphasized the dominance of single/few species with increasing altitude (as was revealed by Simpson's index). The Shannon–Wiener index showed higher diversity on the RTEs of lower altitudes and lower diversity on the RTEs of higher altitudes.

5 Conclusion

The present study highlights the lower elevational RTEs had comparatively higher number of species, whereas lower numbers of species were recorded at higher elevational RTEs, which imply the climatic adaptation by plant species. The findings of this study will provide the baseline data to assess future migration of species. Vegetation response to recent climatic changes on the RTEs is dependent on initial species composition, vegetation structure and environmental conditions. Study results of species distribution will directly reveal the future species shift in Himalayan region and thus will be helpful for planning management and conservation of biodiversity in Himalaya.

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