



Forest structure, diversity and regeneration potential along altitudinal gradient in Dhanaulti of Garhwal Himalaya

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Abstract

Aim of the study: The aim of the present study was to understand the forest composition, structure, diversity and regeneration potential along altitudinal gradient.

Area of study: The study was carried out in Dhanaulti forest which falls under temperate region of Garhwal Himalaya in Uttarakhand state, India.

Material and methods: Vegetation analysis was carried out using 10 quadrats at each altitude using a quadrat size of 10×10 m². In each quadrat, categories of trees >30 cm dbh were considered as trees, 10-30 cm dbh as saplings and <10 cm dbh as seedlings. The data were quantitatively analyzed.

Main results: In upper and middle altitudes, *Cedrus deodara* was reported dominant tree whereas, in lower altitude *Quercus leucotrichophora* was reported dominant. Tree density was highest in lower altitude which reduced middle and upper altitudes whereas, total basal cover increased with increasing altitude. The increasing total basal cover with altitude could be because of the presence of *Cedrus deodara* trees having higher girth classes. In tree, sapling and seedling layers, diversity (H) and equitability (EC) decreased with increasing altitude. However, concentrations of dominance (CD) and beta diversity (BD) have shown reverse trend with H and EC which increased with increasing altitudes, in each layer of tree, sapling and seedling.

The distribution pattern of most species in all layers of trees, saplings and seedlings was contagious. The regeneration potential of the species has shown that some of the species in the absence of tree layer are still regenerating particularly, *Rhododendron arboreum*, *Benthameia capitata*, *Neolitsea pallens* etc. It indicates that most of the species are shifting upward as they are getting suitable conditions.

Research highlights: Altitude influences species composition, diversity and regeneration potential of species.

Keywords: Distribution pattern; tree diversity; regeneration; mountains; temperate; Himalaya.

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Introduction

The Garhwal Himalaya is one of the hot spots of biodiversity situated in the western part of Central Himalaya, showing wide altitudinal range, rapid change in altitudinal gradient even at small distances and high endemism which makes it interesting for studies (Singh & Singh, 1992; Zobel & Singh, 1997; Chandra *et al.*, 2010). Garhwal Himalaya is considered a source of knowledge for unique vegetational wealth since time immemorial. The vegetation diversity of forest ecosystems of Himalaya is influenced by topography, soil,

climate and geographical location (Chandra *et al.*, 2010). There is a great diversity in the floristic pattern due to altitudinal variation and rainfall (Arora, 1995). The biodiversity varies with change in latitude or altitude, as we move from high to low latitude the biological diversity increases. Similarly, a decrease in species diversity is noticed from lower to higher altitudes on a mountain in terrestrial environment (Singh *et al.*, 1994).

Garhwal Himalaya due to ridge-mountains and variable topography supports luxuriant vegetation ranging from sub-tropical to alpine. The elevational

range from 300-2200 m in the Garhwal Himalaya reflects three vegetation zones, viz., *Shorea robusta* in sub-montane zone (upto 1000m) *Quercus leucotrichophora* (>1500) in the low montane to mid-montane zones and *Pinus roxburghii* regime in between the first two zones. Vegetation between 2200 and 2800 m exhibits a dense canopy of *Quercus floribunda* and intermediate range between *Q. leucotrichophora* and *Q. semecarpifolia*. Above 2800 m oak-conifer association occurs where *Q. semecarpifolia*, *Abies pindrow*, *Rhododendron barbatum*, *Taxus wallichiana* and species of *Viburnum* are dominant (Bhandari *et al.*, 2000).

The plant community of a region is a function of time; however, altitude, slope, latitude, aspect, rainfall, and humidity play a role in the formation of plant communities and their composition (Kharkwal *et al.*, 2005). The future composition of the forests depends on the potential regenerative status of tree species within a forest stand in space and time (Henle *et al.*, 2004).

Regeneration of any species is confined to a peculiar range of habitat conditions and the extent of those conditions is a major determinant of its geographic distribution (Grubb, 1977). The population structure, characterized by the presence of sufficient population of seedlings, saplings and adults, indicates successful regeneration of forest species (Saxena & Singh, 1984), and the presence of saplings under the canopies of adult trees also indicates the future composition of a community (Austin, 1977; Pokhriyal *et al.*, 2010).

In an earlier study on species composition and community structure of 23 forest stands in Kumaon Himalaya between altitudes of 1500-3000 m, Hussain *et al.* (2008) have shown that the distribution of the tree communities in these forest stands was governed mainly by the gradients of altitude, slope and canopy cover. Ram *et al.* (2004), in a study on plant diversity in Uttarakhand have inferred that anthropogenic disturbances are changing the species richness and diversity, which influences the soil and environmental conditions. Khera *et al.* (2001) have also studied plant biodiversity assessment in relation to disturbances of forest in Central Himalaya. Uniyal *et al.* (2010) have studied plant diversity of two forest types along the disturbance gradient in Dewalgarh Watershed, Garhwal Himalaya. Singh & Singh (1992) have summarized the information on the structure and functioning of the Himalayan forest ecosystems. Gairola *et al.* (2008) have studied forest vegetation patterns along an altitudinal gradient in sub-alpine zone of west Himalaya, India at an altitude ranging from 2800-3600m. The results revealed that from low to

high altitude strata, size and density of trees declined sharply.

The Garhwal Himalayas embodies a number of forest types that are distributed at various altitudes, geological formations and soil types (Champion & Seth, 1968). The present study is focused in temperate forest of Western and Central Himalaya which are usually distributed from 1200 to 3000 m asl, and characterized by extensive oak and coniferous forests (Kumar & Bhatt, 2006). The studies on forest composition, structure, plant diversity and regeneration of Himalayan forests generally from different parts have been studied but particularly in Dhanaulti forest of present study area of Garhwal Himalaya has so far not been analysed by any researcher along altitudinal gradients. The hypothesis of the study was that: (i) Do composition and structure of forest stand change with increasing elevation and subsequently the regeneration of each species change with increasing elevation. (ii) Does species diversity change with increasing elevation? To test the hypothesis, the following objectives were selected: (i) To study composition, structure and regeneration potential of forest stand along altitudinal gradient. (ii) To study forest stand diversity pattern with increasing elevation.

Materials and methods

Study area

The present study was carried out on forest species composition and structure along altitudinal gradient at three different altitudes of woody tree species in the forest near Dhanaulti in Garhwal Himalaya of Uttarakhand (Figure 1. Location Map of the study area). Dhanaulti is located in the Garhwal Hills between 30° 27' 0" N 78° 15' 0" E and the study area falls between N30° 24' 43" E078° 17' 89" N30° 25' 336" E078° 17' 811" (Table 1). The place is about 2 hour's journey from capital city of Dehradun and is situated at an altitude of 2286 m. The forests have thick trees covers of *Cedrus deodara*, *Quercus leucotrichophora*, *Rhododendron arboreum* *Pinus roxburghii*, etc. The moist *Cedrus deodara* Deodar forest (Type -12/C₁C; Champion and Seth 1968) is found between altitudes 1750-2150 m a.s.l. *Cedrus deodara* is mainly observed in pure patches, while few scattered individuals of other associated species such as *Quercus leucotrichophora*, *Pinus wallichiana*, *Cupressus torulosa* and *Rhododendron arboreum* are also found.

Three sites (Figure 2) on the basis of altitudes were categorized i.e., upper altitude, middle altitude and

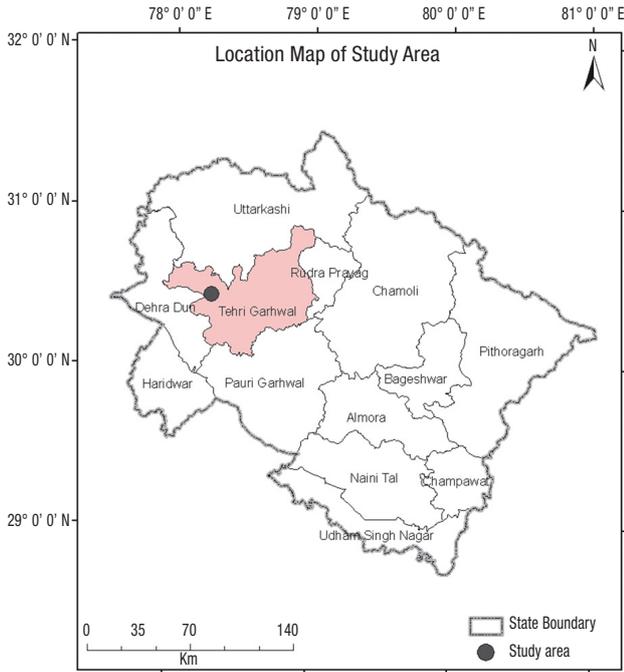


Figure 1. Location map of the study area in Uttarakhand.

lower altitude (Table 1), selected for the study. The soils of this region vary according to aspect, altitude and climate, and are generally young and thin. Due to sharp variations in geocological conditions, the soils of this region do not form a complete group.

Soils of Dhanaulti area belong to mollisols and of Satengal to inceptisols. All these polypedons are members of fine sandy loam, mixed, messic family. These soils developed from different parent materials are in equilibrium with geogenic factors. All pedogenic processes are active in the study area. The soils are generally acidic in nature with pH increasing with depth.

The climatic data of the study area are given in Figure 3. The temperature in this town is cool throughout the year. The summer months are cool. The winters are not very freezing but provide a misty view of distant mountains. The summer temperatures range from 31 °C to 7.5 °C while the winter temperature ranges from 7 °C to 1 °C.

Methodology adopted

Vegetation composition, structure and diversity

The vegetation analysis was carried out in the year of 2012-13. Vegetation analysis in study area was carried out in the tree layer by using 10×10 m² quadrats at three different altitudes. The size and number of quadrats were determined by the species area curve (Misra, 1968) and the running mean methods (Ker-

Table 1. Location of the study area.

Location	Altitude	Geographic's	Elevation (m asl)	Aspect
Dhanaulti	Upper	N30° 24' 434" E078° 17' 894"	2350	North west
	Middle	N30° 25' 209" E078° 17' 867"	2200	North west
	Lower	N30° 25' 336" E078° 17' 811"	2050	North



Figure 2. Google earth view of the study area (LA = Lower altitude; MA = Middle altitude and UA = Upper altitude).

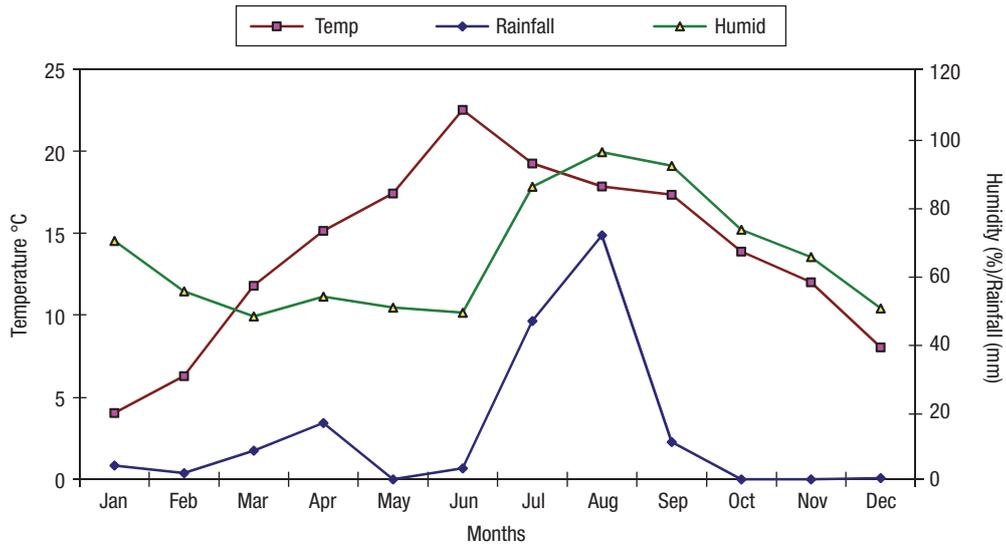


Figure 3. Meteorological data of the study area.

shaw, 1973). In each altitude 10 randomly placed quadrats of square shapes were used for vegetation analysis. Between each site, along the elevation gradient there was 150 m of separation. Due to steep slope and difference in terrain the quadrats were selected randomly to avoid the missing information of the area and problem to move in single direction of transect.

The categories of trees, in each quadrat was based on individuals >30 cm at gbh (girth at breast height) were considered as trees, 10-30 cm gbh as saplings and <10 cm gbh as seedlings. The vegetation data were quantitatively analyzed for abundance, density and frequency (Curtis & McIntosh, 1950). The two categories of trees i.e., 10-30 cm cbh and <10 cm gbh were considered for regeneration. The trees were further divided into twelve girth classes i.e., 31-50, 51-70, 71-90, 91-110, 111-130, 131-150, 151-170, 171-190, 191-210, 211-230, 231-250, and 251-270 cm for density and diameter distribution of trees.

Frequency expresses the distribution or dispersion of species in a community and was calculated as follows:

$$\text{Frequency (\%)} = \frac{\text{Number of quadrats in which the species occurred}}{\text{Total number of quadrats studied}} \times 100$$

The density is defined as the number of individuals per unit area or volume and calculated as:

$$\text{Density} = \frac{\text{Number of individuals of a species in sampling units}}{\text{Total number of sampling units studied}}$$

Abundance refers to density of individuals of a species in those sampling units only, in which a given species occurs and was calculated as follows:

$$\text{Abundance} = \frac{\text{Total number of individuals of a species}}{\text{Total number of sampling units, in which species occurred}}$$

Abundance to frequency ratio (A/F ratio) for different species was used to determine the distribution pattern in terms of regular (<0.025), random (0.025-0.05) and contagious (>0.05), as described by Curtis and Cottam (1956).

Girth at breast height (GBH) was measured at 1.37 m above ground level.

$$\text{Basal area} = \frac{(\text{GBH})^2}{4\pi}$$

$$\text{Mean basal area (MBA)} = \frac{\text{Basal area of all individuals of species}}{\text{Total number of individuals of species}}$$

Total basal cover (TBC) refers to the mean basal cover multiplied with respective density to obtain total basal cover (TBC m² ha⁻¹). Total basal cover (TBC) = Mean basal area of species × density of species.

The importance value index (IVI) was determined as the sum of the relative frequency, relative density and relative dominance (Curtis, 1959).

Species diversity (H) was calculated using following formula as described by Shannon and Wiener (1963):

$$H = - \sum_{i=1}^s (ni/N) \log_2 (ni/N)$$

Where ni = number of individuals of each species, N = total number of individuals of all species.

Concentration of dominance (CD) was determined as described by Simpson's index (Simpson, 1949) as:

$$CD = \sum_{i=1}^s (ni/N)^2$$

Where, n_i and N are same as for Shannon Wiener information function.

The equitability (EC) was calculated as per method described by Whittaker (1975) using density values and the following formula:

$$EC = S/\log(n_i - n_s)$$

Where S = number of the species in the site, and N_i and N_s are the density values of the most and least important species respectively in the site. Beta diversity (BD) was calculated following Whittaker (1975) as follows:

$$BD = S_c/S$$

Where, S_c = alpha diversity (species number or species richness), and

$$S = \frac{\text{Total number of species in all sampling units}}{\text{Total number of sampling units}}$$

Dominance diversity (D-D) curves for trees were plotted by a co-ordinate point method by placing IVI on y-axis, and its position in the sequence of species from highest to lowest IVIs on x-axis (Whittaker, 1975).

Index of similarity (IS) has been estimated for species with the help of Bray-Curits Cluster Analysis using SPSS-16.0 version software. Statistical analysis was

carried out by General statistical-32 with one way and two way anova is used.

Results

Community composition and structure

The composition and structure of selected forest sites were studied at three different altitudes for tree, sapling and seedling layers. The details of each layers at different altitude is shown in Table 2.

Tree layer

In the upper altitude, based on IVI values *Cedrus deodara* was reported dominant species followed by *Quercus leucotrichophora* and *Q. floribunda*. The maximum values of frequency and density were also recorded for *Cedrus deodara* followed by *Quercus leucotrichophora* and *Q. floribunda*. The maximum and minimum values of total basal cover were again observed for *Cedrus deodara* and *Q. floribunda* respectively. All the tree species in this altitude were distributed contagiously (Table 2).

In middle altitude, *Cedrus deodara* was again reported dominant with highest IVI value followed by

Table 2. Frequency (%), Density (ind ha⁻¹), TBC (m² ha⁻¹), IVI and A/F ratio of trees, saplings and seedlings in different altitudes.

Altitude/Species	Tree					Sapling					Seedling				
	Frequency	Density	TBC	IVI	A/F ratio	Frequency	Density	TBC	IVI	A/F ratio	Frequency	Density	TBC	IVI	A/F ratio
Upper Altitude															
<i>Cedrus deodara</i>	100	700	127.08	237.35	0.070	-	-	-	-	-	-	-	-	-	-
<i>Quercus leucotrichophora</i>	40	90	7.17	40.80	0.056	50	250	0.45	197.71	0.100	40	160	0.09	138.55	0.100
<i>Quercus floribunda</i>	20	60	3.15	21.85	0.150	20	40	0.06	42.42	0.100	10	10	0.01	15.54	0.100
<i>Benthamedia capitata</i>	-	-	-	-	-	20	30	0.06	38.08	0.075	30	80	0.03	67.72	0.089
<i>Rhododendron arboreum</i>	-	-	-	-	-	10	20	0.04	21.80	0.200	40	90	0.03	78.20	0.056
Middle Altitude															
<i>Cedrus deodara</i>	90	240	35.67	118.09	0.030	-	-	-	-	-	-	-	-	-	-
<i>Quercus leucotrichophora</i>	100	370	13.99	98.99	0.037	80	140	0.37	93.10	0.022	50	70	0.03	47.80	0.028
<i>Quercus floribunda</i>	40	80	2.46	26.17	0.050	40	120	0.42	75.84	0.075	50	180	0.07	83.88	0.072
<i>Rhododendron arboreum</i>	40	70	2.06	24.31	0.044	50	110	0.16	57.58	0.044	40	100	0.05	59.76	0.063
<i>Lyonia ovalifolia</i>	30	60	3.24	22.04	0.067	10	10	0.05	10.38	0.100	-	-	-	-	-
<i>Benthamedia capitata</i>	10	20	0.26	5.93	0.200	30	50	0.12	32.81	0.056	40	110	0.05	57.81	0.069
<i>Neolitsea pallens</i>	10	10	0.10	4.47	0.100	20	50	0.14	30.28	0.125	40	110	0.03	50.75	0.069
Lower Altitude															
<i>Quercus leucotrichophora</i>	100	440	12.23	91.39	0.044	80	370	1.16	108.29	0.058	80	250	0.07	67.86	0.039
<i>Lyonia ovalifolia</i>	90	350	9.64	75.32	0.043	50	170	0.58	55.64	0.068	-	-	-	-	-
<i>Rhododendron arboreum</i>	70	230	6.56	52.94	0.047	60	130	0.40	48.01	0.036	90	330	0.06	75.18	0.041
<i>Pinus roxburghii</i>	50	60	11.73	45.32	0.024	20	50	0.21	19.70	0.125	-	-	-	-	-
<i>Quercus floribunda</i>	50	110	3.16	29.85	0.044	50	110	0.21	35.89	0.044	70	200	0.03	48.64	0.041
<i>Benthamedia capitata</i>	10	20	0.36	5.18	0.200	30	50	0.13	19.71	0.056	60	180	0.04	48.09	0.050
<i>Neolitsea pallens</i>	-	-	-	-	-	20	40	0.05	12.76	0.100	60	230	0.07	60.24	0.064

Quercus leucotrichophora, *Q. floribunda*, *Rhododendron arboreum*, *Lyonia ovalifolia*, *Benthamidia capitata* and *Neolitsea pallens*. The maximum value of frequency and density was recorded for *Quercus leucotrichophora*, however, the highest and lowest values of total basal cover was recorded for *Cedrus deodara* and *Neolitsea pallens* respectively (Table 2). The distribution pattern of *Cedrus deodara*, *Quercus floribunda*, *Quercus leucotrichophora* and *Rhododendron arboreum* was random, whereas, *Benthamidia capitata*, *Lyonia ovalifolia* and *Neolitsea pallens* were distributed contagiously (Table 2).

In lower altitude, *Quercus leucotrichophora* was reported as dominant species with highest value of IVI. The maximum frequency, density and total basal area was also recorded for *Quercus leucotrichophora* while minimum frequency, density and total basal area for *Benthamidia capitata*. The distribution pattern of most of the species i.e., *Quercus leucotrichophora*, *Q. floribunda*, *Rhododendron arboreum* and *Lyonia ovalifolia* was reported random while *Benthamidia capitata* was distributed contagiously and the distribution pattern of *Pinus roxburghii* was regular (Table 2). Tree showing variation in frequency, total basal cover and A/F ratio with different altitudes are significant at ($p < 0.05$), while density and IVI were insignificant with different altitudes (Table 3).

Sapling layer

In upper altitude, the saplings of *Quercus leucotrichophora* were dominant with highest value of IVI, followed by *Q. floribunda*, *Benthamidia capitata* and *Rhododendron arboreum*. Maximum values of frequency

and density were recorded for *Quercus leucotrichophora* however, maximum and minimum values of total basal area were recorded for *Quercus leucotrichophora* and *Rhododendron arboreum* respectively. All the saplings in this altitude were distributed contagiously.

In middle altitude, the most dominant species was *Quercus leucotrichophora* and the least dominant was *Lyonia ovalifolia*. The maximum density was reported for *Quercus leucotrichophora* followed by *Quercus floribunda*, *Rhododendron arboreum*, *Benthamidia capitata*, *Neolitsea pallens* and *Lyonia ovalifolia*. The highest and lowest total basal cover was recorded for *Quercus floribunda* and *Lyonia ovalifolia* respectively. *Quercus floribunda*, *Benthamidia capitata*, *Lyonia ovalifolia*, *Neolitsea pallens* were distributed contagiously while, *Quercus leucotrichophora* and *Rhododendron arboreum* were distributed in regular and random patterns respectively.

In lower altitude, the dominant species was *Quercus leucotrichophora* followed by *Lyonia ovalifolia*, *Rhododendron arboreum*, *Quercus floribunda*, *Benthamidia capitata*, *Pinus roxburghii* and *Neolitsea pallens*. The values of frequency, density and total basal area were recorded maximum for *Quercus leucotrichophora* while the minimum values of density and total basal area were observed for *Neolitsea pallens* however, minimum value of frequency was recorded for *Neolitsea pallens* and *Pinus roxburghii*. On this altitude all the species were distributed contagiously except *Quercus floribunda* and *Rhododendron arboreum* which were distributed randomly (Table 2). The variation in frequency along altitude is significant at ($p < 0.05$) while density and total basal cover of saplings is significant at ($p < 0.01$) among different altitudes while IVI and A/F ratio was insignificant with different altitudes (Table 3).

Table 3. Trees, seedlings and saplings showing variation in Frequency (%), Density (ind ha⁻¹), TBC (m² ha⁻¹), IVI and A/F ratio with different altitude (Level of significance * $p < 0.05$, ** $p < 0.01$ and *** $p < 0.001$).

Layer		Altitude			Level of significance	CD
		Upper	Middle	Lower		
Tree	Frequency	25.00	43.33	52.86	*	
	Density	83.33	140.22	211.67	NS	
	TBC	0.050	0.227	0.239	*	
	IVI	41.00	39.99	34.17	NS	
	A/F ratio	0.101	0.061	0.626	*	
Sapling	Frequency	25.00	43.33	52.85	*	17.235
	Density	45.00	96.67	140.00	**	59.22
	TBC	0.050	0.230	0.240	**	0.101
	IVI	41.00	40.00	34.17	NS	
	A/F ratio	0.101	0.060	0.062	NS	
Seedling	Frequency	30.00	44.00	72.00	***	15.13
	Density	85.00	114.00	238.00	**	71.52
	TBC	0.040	0.046	0.054	NS	
	IVI	74.25	60.00	60.00	NS	
	A/F ratio	0.086	0.06	0.047	***	0.022

Seedling layer

In upper altitude, the dominant species was *Quercus leucotrichophora* followed by *Rhododendron arboreum*, *Benthamia capitata* and *Quercus floribunda*. The maximum and minimum values of density were recorded for *Quercus leucotrichophora* and *Quercus floribunda* respectively. The highest value of total basal area was reported for *Quercus leucotrichophora* followed by *Benthamia capitata*, *Rhododendron arboreum* and *Quercus floribunda*. All the seedlings in this altitude were distributed contagiously.

In middle altitude, the dominant species was *Quercus floribunda*. Other species in decreasing order of IVI were *Rhododendron arboreum*, *Benthamia capitata*, *Neolitsea pallens* and *Quercus leucotrichophora*. The value of frequency was 50% for *Quercus floribunda* and *Quercus leucotrichophora* and 40% for *Benthamia capitata*, *Rhododendron arboreum* and *Neolitsea pallens*. The highest and lowest values of density were reported for *Quercus floribunda* and *Quercus leucotrichophora* respectively. The total basal cover was reported maximum for *Quercus floribunda* followed by *Benthamia capitata*, *Rhododendron arboreum*, *Quercus leucotrichophora* and *Neolitsea pallens*. Almost all seedlings were distributed contagiously except *Quercus leucotrichophora* which was distributed randomly.

In lower altitude, the seedlings of *Rhododendron arboreum* were dominated with highest values of IVI. The maximum frequency was reported for *Rhododendron arboreum* whereas, minimum value was reported for two species (*Benthamia capitata* and *Neolitsea pallens*). The maximum and minimum values of density were reported for *Rhododendron arboreum* and *Benthamia capitata* respectively. The maximum total basal cover was for *Neolitsea pallens* and *Quercus leucotrichophora* followed by *Rhododendron arboreum*, *Benthamia capitata* and *Quercus floribunda*. The distribution pattern of all the species reported was random except *Neolitsea pallens* which was distributed contagiously (Table 2). Seedling showing variation in frequency and A/F ratio along altitude is significant at ($p < 0.001$), while density is significant at ($p < 0.01$) and total basal cover and IVI are insignificant with different altitude (Table 3).

Species diversity (H), concentration of dominance (CD), equitability (EC) and Beta diversity (BD)

The species diversity values for trees, saplings and seedlings at different altitudes i.e., upper altitude, middle altitude and lower altitude have been given in

Table 4. In tree layer, species diversity was reported equal ($H = 2.13$) in both middle and lower altitudes which were higher compared to upper altitude where, species diversity reported of $H = 0.84$. In sapling layer, the reported values of diversity reduced with increasing altitudes as $H = 2.40$, $H = 2.30$ and $H = 1.24$ for upper, middle and lower altitudes respectively. Similarly the species diversity in seedling layer ranged from $H = 1.66$ (upper altitude) to $H = 2.29$ (lower altitude).

The CD values for tree layer increased with increasing altitude ranging from 0.26 to 0.69 (Table 4). The maximum and minimum values of CD in sapling layer reported were 0.57 and 0.22 respectively, whereas, in seedling layer the CD values again increased with increasing altitude (Table 3).

In each layer of trees, saplings and seedlings, the EC reduced with increasing altitudes from lower altitude to upper, where the values reported for each layer varied from 2.81 to 4.47 (for tree layer) 3.65 to 7.25 (for sapling layer) and 3.32 to 18.99 (for seedling layer) (Table 4).

The results for beta diversity (BD) shows that in each layer (trees, saplings and seedlings), the values of BD were reported reverse of CD. These values of BD increased with increasing altitudes from lower to upper altitudes (Table 4).

Similarity index

Similarity among species at different stages of vegetation was observed in different clusters as per Bray-Curtis analysis (Figure 4a, 4b, 4c). At tree stage maximum numbers of individuals were recorded for *Cedrus deodara* (94) and *Quercus leucotrichophora* (89) followed by *Lyonia ovalifolia* (38), *Rhododen-*

Table 4. Species diversity (H), concentration of dominance (CD), equitability (EC), beta diversity (BD) of different layers in different altitudes.

Layer/Altitude	H	CD	EC	BD
Tree				
Upper Altitude	0.84	0.69	2.81	3.12
Middle Altitude	2.13	0.29	4.46	2.25
Lower Altitude	2.13	0.26	4.47	2.18
Sapling				
Upper Altitude	1.24	0.57	3.65	4.0
Middle Altitude	2.30	0.22	5.24	2.60
Lower Altitude	2.40	0.24	7.25	2.41
Seedling				
Upper Altitude	1.66	0.35	3.32	3.84
Middle Altitude	2.25	0.22	12.19	2.27
Lower Altitude	2.29	0.21	18.99	0.14

dron arboreum (30) and *Quercus floribunda* (25) cluster, while a separate cluster of *Benthamidia capitata* (4) and *Nelolitseia pallens* (1) indicated minimum number of individuals at tree stage (Figure 4a). In the sapling stage, *Quercus leucotrichophora* (75) showed highest number of individuals. *Quercus floribunda* (27) and *Rhododendron arboreum* (25) showed almost similar number of individuals at sapling stage, while lowest individuals (3) were recorded for *Pinus roxburghii* at the sapling stage (Figure 4b). At seedling stage *Rhododendron arboreum* (49) and *Quercus leucotrichophora* (48) showed maximum number of individuals forming a separate cluster followed by *Quercus floribunda* (39) and *Nelolitseia pallens* (35), while for *Cedrus deodara* only 1 individual was recorded at seedling stage which indicates poor regeneration of this species in the study area (Figure 4c).

Discussion

The plant community of a region is a function of time; however, altitude, slope, latitude, aspect, rainfall and humidity also play a role in the formation of plant communities and their composition (Kharkwal *et al.*, 2005) including soil properties, biotic factors, disturbance history etc. Variation in species diversity along environmental gradient is an important topic of ecological investigation and has been explained by reference to climate, productivity, biotic interaction, habitat heterogeneity and history (Willig *et al.*, 2003; Qian & Ricklefs, 2004; Gairola *et al.*, 2008).

Forest composition and structure

In the present study, tree density ranged from 850 to 1210 trees ha⁻¹ and total basal cover of trees ranged between 43.68 to 137.4 m² ha⁻¹. In the world forests, Duvigneaud & Denayer-De Smet (1970) and Dabel & Dey (1977) reported total basal cover values ranging from 12.2 to 83.8 m² ha⁻¹ for montane temperate forest of world. Valencia *et al.* (1994) reported the density values between 716 to 1440 ha⁻¹ for Kurupukari forest in Guyana and density of terra firm forest as 1561 ha⁻¹ respectively. Kunwar & Sharma, (2004) carried out a study in Dolpa district of mid-west Nepal, where the density values reported from 2090 to 2100 ind ha⁻¹.

In Kumaun Himalayan forests in Uttarakhand, Bargali *et al.* (1987) described the density values from 490 to 1640 ha⁻¹ in different pine forest. Ralhan

et al. (1982) reported mean density value of 416 trees ha⁻¹ and mean total basal cover value of 32.71 m² ha⁻¹. Saxena & Singh (1982) carried out a study in *Quercus floribunda* forest and reported the density and total basal cover values of 1300 ha⁻¹ and 29.40 m² ha⁻¹ respectively. Bharali *et al.* (2011) reported tree density ranging between 707 to 963 ind. ha⁻¹. Saxena & Singh (1982) reported density values ranging from 420 to 1640 ind. ha⁻¹ for temperate forests. The values carried out in the present study fall within the range of values reported by researchers in the Kumaun Himalayan forests.

In a study of Kumar & Bhatt (2006) in Garhwal Himalayan temperate oak mixed forest reported density and total basal cover values ranging from 760 to 1110 trees ha⁻¹ and 38-56.62 m² ha⁻¹ respectively. Kumar *et al.* (2009) also reported the density and total basal cover values of 652 to 1028 m² ha⁻¹ and 11.38 to 31.70 m² ha⁻¹ respectively in a temperate forest. Sharma *et al.* (2011) studied in temperate forest on various slope aspects showing variation in stem density, tree biomass, where stem density was lowest on north east aspect in moist *Cedrus deodara* forest type (380 ± 34.2 ind. ha⁻¹) and highest on north east aspect in *Quercus leucotrichophora* forest type (1360 ± 105.6 ind ha⁻¹). Bhandari & Tiwari (1997) reported density values from 1570–1785 ind ha⁻¹ in Himalayan temperate forests. These values reported by above experts for Garhwal Himalayan forests are fluctuating above and below the values of the present study, due to different levels of disturbances in the forests. Many researchers (Baduni & Sharma, 1996; Ghildiyal *et al.*, 1998; Sharma & Baduni, 2000; Ram *et al.*, 2004) reported basal area values ranging from 17.9 to 180.1 m² ha⁻¹ in the temperate forest of Himalaya. In different forest types of Garhwal Himalaya, Raturi (2012) reported highest value of density (1980 plant ha⁻¹) in the temperate mixed forest and minimum value of density (1090 plant ha⁻¹) in sub-tropical forest. However, among the other forests, total basal area was maximum in *Pinus roxburghii* (43.62 m² ha⁻¹) of sub-tropical mixed forest and minimum in *Q. glauca* (3.182 m² ha⁻¹) temperate forest. Dhaulakhandi *et al.* (2008) reported density value of 820 trees ha⁻¹ in natural forest of Gangotri. Devlal & Sharma (2008) reported total density of trees ranging from 1166 trees ha⁻¹ to 1826 trees ha⁻¹. This study revealed that *Quercus leucotricophora* was the most dominant species of all stands. Oak forests are most extensively distributed between the altitudes 1000m to timberline and represent the climax stage, throughout the Central Himalaya (Champion & Seth, 1968; Upreti *et al.*, 1985).

Distribution Pattern (%)

The distribution pattern of all the species in upper altitude showed contagious distribution, however, in middle altitude majority of the species were distributed contagiously and few species were random in distribution whereas no species reported showing regular distribution. In lower altitude, random distribution was reported dominant. In saplings and seedlings layers majority of species were distributed contagiously.

The present study revealed that majority of species in tree sapling and seedling layers were distributed contagiously. Odum (1971) also suggested that contagious distribution is the commonest pattern in nature, whereas, random distribution occurs only in a very uniform environment, and regular distribution occurs when severe competition occurs between individuals. Many workers (Greig-Smith, 1957; Kershaw, 1973; Singh & Yadav, 1974; Kumar & Bhatt, 2006) have also reported contagious distribution for Himalayan forests. Rawat & Chankhok (2009) reported distribution pattern of tree, sapling and seedling layers indicating that most of the species are distributed randomly, while some species of trees and saplings were regular in distribution, however, in tree layer few of them were distributed contagiously with absence of contagious distribution in saplings. Raturi (2012) studied four forest types of Himalaya and reported tree distributed randomly, while shrub layer revealed random and regular distribution patterns.

Species richness

In tree layer, species richness ranged from 3 species for upper altitude and 7 species for middle altitude, whereas, 6 species reported for lower altitude. Middle site has indicated highest number of species which favour higher number of species compared to both upper and lower. Parthasarathy (1999) reported species richness of 144 species in a tropical wet evergreen forest of Kalakad National Park in Western Ghats. Bhuyan *et al.* (2003) reported species richness of 54 species in a tropical wet evergreen forest of Arunachal Pradesh. Semwal *et al.* (2010) reported maximum tree richness (10 species) in *Rhododendron arboreum* dominated forest and minimum (8 species) in *Q. leucotrichophora* forest. Raturi (2012) recorded the species richness between 2-13 species for trees. Nath *et al.* (2005) recorded that the tree species richness decreased with increase in the intensity of disturbance. Although present study has quite lower number of species richness which showed negative relationship with altitude. Sharma *et al.* (2009) also reported negative relation of

tree species richness index with increasing altitude. The decrease in diversity and species richness at high elevation strata could be due to ecophysiological constraints, such as reduced growing season, low temperature and low productivity (Korner, 1998; Gairola *et al.*, 2008). Other factors such as soil fertility and topography may also affect the patterns of species richness along altitudinal gradient (Gairola *et al.*, 2008). Rahbek (1995) presented a critical literature review on species richness patterns in relation to altitude and showed that approximately half of the studies detected a mid-altitude peak in species richness (Grytnes & Vetaas 2002).

Grytnes & Vetaas (2002) compare different null models for species richness patterns in the Nepalese Himalayas. Species richness is estimated by interpolation of presences between the extreme recorded altitudinal ranges. The number of species in 100-m altitudinal bands increases steeply with altitude until 1,500 m above sea level. Between 1,500 and 2,500 m, little change in the number of species is observed, but above this altitude, a decrease in species richness is evident.

Singh *et al.* (1994) reported that *Pinus roxburghii*-mixed broadleaved forests had the highest species richness, while high elevation forests had the lowest. Other researchers such as Burns (1995) and Austin *et al.* (1996) have found that the total species richness was greatest at lower elevation and warmer sites. The overall pattern of species richness showed a sharp decline as the altitude increased beyond 3000 m asl (Sharma *et al.*, 2009).

Species diversity (H)

In the present study the species diversity of trees, saplings and seedlings at different altitudes ranged from 0.84 to 2.13 (for trees), 1.24 to 2.40 (for saplings) and 1.66 to 2.29 (for seedlings). The results showed that diversity of trees, saplings and seedlings generally decreased with increasing altitudes. Semwal *et al.* (2010) reported species diversity (H) in different forest types varying between 0.75 to 0.96 (for tree), 1.22 to 2.46 (for shrub) and 1.96 to 3.12 (for herb). Overall, *Q. semecarpifolia* forest showed maximum diversity (H = 0.96) and *Rhododendron arboreum* mixed forest exhibited minimum diversity (H = 0.75) values. The values of species diversity of trees are comparatively lower than those of the present study. Singh & Singh (1987) also reported diversity values (H = 1.19 to 2.15) in chir pine mixed forest of Central Himalaya. Rawat & Chandhok (2009) reported species diversity ranging from 1.9 to 2.24. Gairola *et al.*

(2008) carried out study in Pindari, Lata and Tungnath areas at <3000m, 3000-3200m and >3200m elevations and reported highest diversity in 3000-3200m and lowest >3200m and reported diversity values for Pindari ($H = 0.44$ to 1.55), Lata ($H = 0.56$ to 1.09) and Tungnath ($H = 0.693$ - 0.87), which have not shown any specific trend with altitude. Raturi (2012) reported species diversity ranging between 0.78 to 3.45 for tree stratum. Maximum diversity ($H = 3.45$) was recorded for temperate mixed forest and minimum ($H = 0.78$) for sub-tropical forest.

Kharkwal *et al.* (2005) carried out a study on phyto-diversity and growth form of plants in relation to altitudinal gradient in the Central Himalayan region of India and reported that along the altitude the geographic and climatic conditions change sharply. Here total number of species, including all growth forms were higher near low altitude to mid altitude of tropical/subtropical belt but with further increase in altitude it decreased consistently due to decrease in atmospheric temperature with increase in altitude.

Gairola *et al.* (2008) reported variation in species diversity (H) along environmental gradient as a major topic of ecological investigation and has been explained by reference to climate, productivity, biotic interaction, habitat heterogeneity and history (Givnish, 1999; Willig *et al.*, 2003; Currie & Francis, 2004; Gonzalez-Espinosa *et al.*, 2004; Qian & Ricklefs, 2004).

Concentration of Dominance (CD)

In the present study the concentration of dominance ranged from 0.26 to 0.69 (for trees), 0.22 to 0.57 for saplings and 0.21 to 0.35 for seedlings. Raturi (2012), reported highest concentration of dominance for subtropical forest ($CD = 0.63$) and the lowest ($CD = 0.09$) for temperate mixed forest. Risser & Rice (1971) reported values between 0.10 to 0.99 for tropical forest. Ahmed (2012) in a study in Ranikhet forest of Uttarakhand the value of concentration of dominance for Oak, Oak-pine, Oak-scrub and chir pine were 0.237 , 0.246 , 0.349 and 0.56 respectively. Sharma *et al.* (2009) in a study on temperate mixed forest along altitudinal gradient reported concentration of dominance values as 0.135 , 0.138 and 0.321 at upper, middle and lower altitudes respectively.

Beta Diversity (BD)

In present study the values of beta diversity ranged between 2.18 to 3.12 for trees, 2.41 to 4.0 for saplings

and 0.14 to 3.84 for seedlings. Semwal *et al.* (1999) in a study on Garhwal Himalayan region reported beta diversity values of 1.304 for trees, 1.53 for saplings and 1.41 for seedlings. Kumar *et al.* (2004) reported the range of values of beta diversity from 1.75 to 15.24 in a oak forest in Garhwal Himalaya. Sharma *et al.* (2009) reported beta diversity values from 2.89 to 3.50 in a temperate forest of Garhwal Himalaya. Raturi (2012) reported the values of beta diversity between 0.40 to 16.90 in four types of forests in Garhwal Himalaya. The reported values of researchers are close to the present study.

Density-diameter distribution

The density-diameter graph of trees in different altitude is shown in Figure 5a, 5b, 5c. Density-diameter distribution has often been used to represent the population structure of forest (Khan *et al.*, 1987; Kumar *et al.*, 2009). The nature of distribution curve

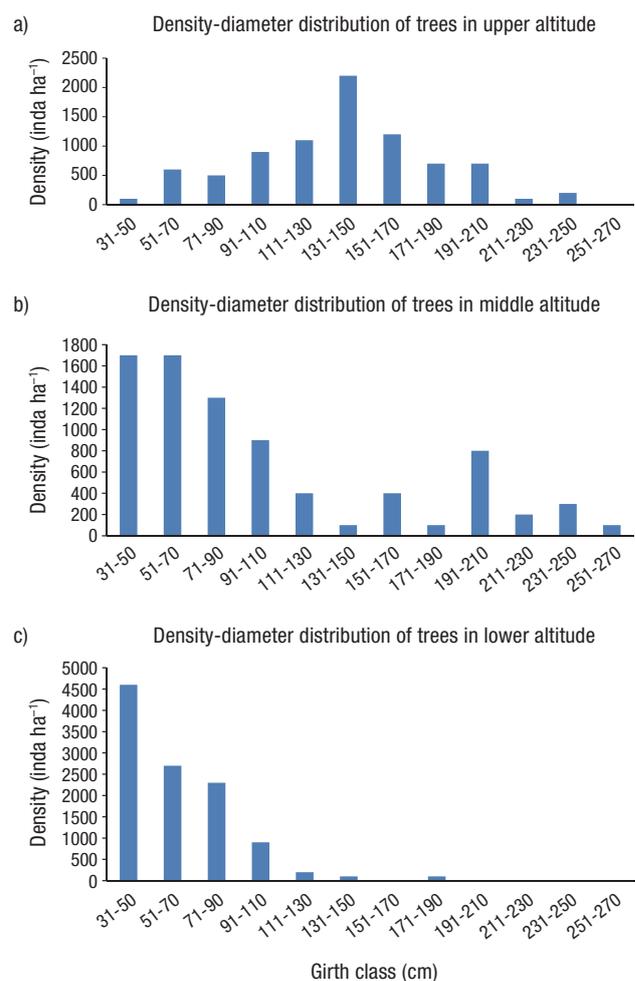


Figure 5. Showing density-diameter distribution of trees under different girth classes in upper, middle and lower altitudes.

can also be used to interpret the character of vegetation. In general, trees with higher girth classes have lower density value. Kumar *et al.* (2009) also reported lower density values with increasing girth classes.

Dominance-diversity curve (D-D Curve)

The dominance-diversity curve for all the vegetation layers i.e., trees, saplings and seedlings have been given in Figures 6a, 6b, 6c. The dominance-diversity curve fit for the lognormal situation (Khera *et al.*, 2001). The lognormal series describes the partitioning of realized niche space among various species and it is consequence of the evolution of diversity in the niche parameters that is exploits (Whittaker, 1965; Khera *et al.*, 2001). Raturi (2012) reported the dominance-diversity curve for tree and shrub layers approached geometric series for all forest types constructed on the basis of importance value index. The lognormal distribution of the forest layer was

due to highly mixed nature of vegetation. The geometric series for both the layers confirmed the niche preemption hypothesis of Whittaker (1975).

Regeneration status

The regeneration pattern of the species is shown in Table 2. In tree layer, *Cedrus deodara* was reported on upper and middle altitudes; however no sapling and seedling were reported, which is indication that in future no further growth may appear in the forest. In lower altitudes, the density of *Quercus leucotrichophora* trees reduced with increasing altitudes as 440 trees ha⁻¹, 370 trees ha⁻¹, 90 trees ha⁻¹. Similarly *Quercus floribunda* also reduced with increasing altitudes. Among the altitudes, *Benthamidia capitata* in tree layer was reported in lower and middle altitudes with sufficient number of saplings and seedlings however, it was interesting to note that enough saplings and seedlings were reported in upper altitude while no single tree was reported in upper altitudes, which indicate the shifting of species towards higher altitude. In tree layer, *Rhododendron arboreum* also reduced with altitudes but not reported in upper altitude, while saplings and seedlings were reported in upper altitude, this also indicates that *Rhododendron arboreum* is shifting upper to upper altitude.

Regeneration status of tree species of any forest is determined by recruitment of saplings and seedlings (Dhar *et al.*, 1997; Singh & Singh, 1992). In a study, Pant & Samant (2012) suggested the number of species in seedling and sapling stages varied from community to community.

The density values of seedlings and saplings are considered as regeneration potential of the species or forest. The presence of good regeneration potential shows suitability of a species to the environment. Climatic factors and biotic interference influence the regeneration of different species in the vegetation. Higher seedling density values get reduced to sapling due to biotic disturbance and competition for space and nutrients. Good & Good (1972) have considered three major components which cause the successful regeneration of tree species. These components are the ability to initiate new seedlings, ability of seedlings and saplings to survive, and ability of seedlings and saplings to grow.

In the seedling and sapling layers the density ranged from 340 to 1190 ind. ha⁻¹ for seedlings and 340 to 920 ind. ha⁻¹ for saplings. The total basal cover values for seedlings and saplings layers were reported from 0.15 to 1.02 m² ha⁻¹ and 0.61 to 2.74 m² ha⁻¹ respectively.

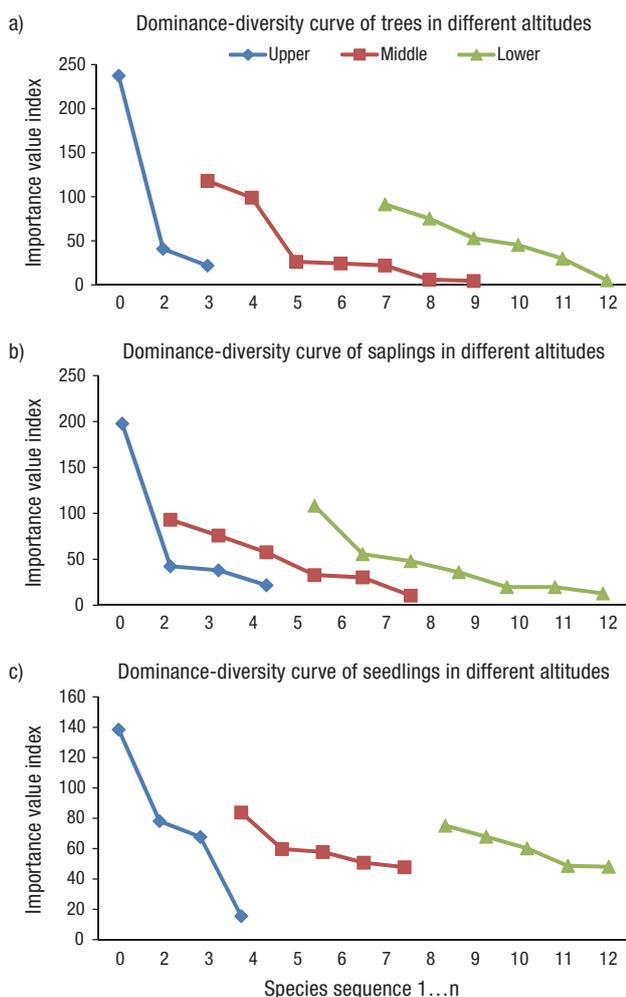


Figure 6. Indicating dominance-diversity curve of trees, saplings and seedlings in different altitudes.

A study by Gairola *et al.* (2008) for different high altitude Himalayan forests reported that among the study sites, maximum seedling density throughout the altitudinal strata in Pindari suggests that the slope and aspect favour regeneration of tree species. However, low temperature, wind direction and snow depth have also been considered the main factors which determine the seed germination and rate of seedling survival (Qingshan *et al.*, 2007).

Rawat & Chandhok (2009) reported saplings and seedlings layer densities ranging from 90 to 410 ind ha⁻¹ for saplings and 50 to 510 ind ha⁻¹ for seedlings. Natural regeneration is a key process for the continued existence of a species in a community. Ability of species to initiate new seedlings, their survival and growth are the three major components of successful regeneration (Good & Good, 1972; Saikia & Khan, 2013). Presence of sufficient number of seedlings, saplings and young trees in a given population indicates successful regeneration (Saxena & Singh, 1984), which is frequently influenced by the biotic interactions and physical factors in the community.

In general, *Pinus roxburghii* and *Quercus leucotrichophora* showed fair regeneration in spite of fire and logging. Tree density showed strong correlations with the densities of seedlings and poles, while saplings density was not significantly correlated that of trees, indicating low sapling density. Observations suggest that conversion of saplings to tree strata is a crucial factor to ensure good regeneration of species in these types of forests.

Conclusion

The study suggests that the Himalayan forests provide various valuable requirements to the human being as well as the association of closed other growing species. In the present study area *Cedrus deodara* is growing in trees stages however, the regeneration is completely absent, which provides information that the forest may disappear in due course of time. Similar case has also been reported for *Lyonia ovalifolia* and *Pinus roxburghii* from middle and lower altitudes. From management point of view the reason of failure of these species should be evaluated for their further survival and association.

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