INNSPUB

International Journal of Biosciences | IJB |
ISSN: 2220-6655 (Print) 2222-5234 (Online)
http://www.innspub.net
Vol. 14, No. 4, p. 316-336, 2019

RESEARCH PAPER OPEN ACCESS

Himalayan temperate forest composition and canopy attributes

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Key words: Temperate moist Himalayan Forest, Structure, *DBH, BA,* Crown attributes.

http://dx.doi.org/10.12692/ijb/14.4.316-336 Article published on April 30, 2019

Abstract

The moist temperate conifer forests in Pakistan are located between N 34°38.38′ latitudes and E 73°33.11′ longitude. The elevation ranges from 1500m to 3000m with a rainfall from 400mm to 800mm. The forest consist of mixture of evergreen *Pinus wallichiana*, *Cedrus deodara*, *Abies pindrow* and *Picea smithiana* with little admixture of broadleaved trees. All these species are capable of attaining good height (27-35m), very considerable girth (44-48cm). Stem and crown parameters were measured for 2880 trees between 2000- 2700m altitude. *DBH* and *BA* increased with increase in elevation while tree height, crown length, crown surface area, crown volume and tree density decreased as elevation increased. Species specific behavior and changing pattern of canopy attributes in relation to altitude in these forests are discussed.

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Introduction

The Himalayan moist Temperate Forests are different from all other forest types in Pakistan in terms of Physiognomy and structure (Champion *et al.* 1965). The chief characteristic of the temperate forest is extensive development of coniferous species including *Abies pindrow*, *Pinus wallichiana*, *Taxus wallichiana, Picea smithiana* and *Cedrus deodara* with varying admixture of evergreen and deciduous patches of broad leaved forests (Champion and Seth, 1965; Hussain and Illahi 1991; Ahmed *et al.* 2006; Saima *et al.* 2009). The forest canopy may be varying from continuous dense to open with gaps of various sizes occupied with grassy patches. The conifer species generally forms a fairly complete forest having good height.

It is generally believed that in mountain landscape the complex gradients in environmental conditions that are associated with elevation and topography result in the differences in the occurrence and dominance of the plant species at landscape scale. Altitude itself creates a complex combination of various ecological gradients such as temperature, rainfall, and wind speed, magnitude of snow accumulation and topographic heterogeneity, which affects the overall forest composition (Kubota *et al.* 2004). In mountain forests, altitudinally defriend geo-climatic factors seemed to be the main determinant of the changes in species assemblage and construction (Whittaker, 1965).

Previous studies on these temperate forests of Pakistan have mainly been floristical and/or phyto-geographical (Champion *et al.* 1965; Beg, 1975; Ahmad 1976, 1986; Hussain and Illahi, 1991; Durrani and Hussain, 2005; Ahmed *et al.* 2006; Saima *et al.* 2009). Less attention has been paid to the changes in canopy attributes along the altitudinal gradient in these forests. Recent studies of altitudinal effects on tree attributes (Baig and Tranquillini, 1976; Korner, 1998; Coomes and Allen, 2007) have concentrated on tree stature (Aiba and Kohyama, 1996), stem diameter (King, 2006) and crown parameters (Thomson *et al.*, 1996; Aiba and Kohyama, 1997). The functional causes which determine the tree height and other canopy attributes along the elevation are still in debate (Miehe *et al.* 2007; Kessler *et al.* 2014).

The interspecific differences in canopy attributes in response to altitude are a general phenomenon and might be attributed to phylogenetic differences among the tree species. Beside the phylogenetic and eco-physiological limitations, canopy attributes may be influenced by several interlinked environmental factors such as temperature, rainfall, water and nutrient availability along the elevation gradient. Little attention has been paid to the causes of the shift of plant canopy attributes along the altitude and topographically induced ecological gradients in Himalayan montane forests.

Present investigations focus on canopy attributes as well as the compositional parameters. We have measured plant height, basal area, bole height, Crown area and crown volume along with tree density, frequency and dominance. These traits are chosen because of their ecological significance. Tree height and crown dimensions are important tree characteristics used in growth measurement (Soares and Tome, 2001). Height-diameter curves for tree species have been long used in forest inventories for predicting forest productivity (Curtis, 1967; Wykoff *et al.* 1982; Huang *et al.* 1992; Gonzalez and Montero, 2007). Crown width is used in tree and crown level growth indices (Vanclay, 1994). Crown surface area and volume is calculated to assess forest health (Zarnoch, *et al.* 2004). Differences in these traits between species are expected to be meaningful, even though each is modulated to some degree in response to environment in which the individual plant develops. It is well known from general observation that species occurring at lower rainfall and lower-nutrient soils tend to be lower in height.

The main objectives of the present investigation are two folds. Firstly, it tries to elucidate the causes of differences in canopy and compositional attributes of moist conifer forests in Himalayan uplands. Secondly, it tries to evaluate the interspecific differences in canopy attributes which have important ecological implications.

Materials and methods

Selection of Sites

Three forest types: Low- Level Blue Pine (*Pinus wallichiana*) Forest (2000m, a.s.l); Mid-Level Moist Deodar (*Cedrus deodara*) Forest (2200m, a.s.l) and Upper West Himalayan Fir (*Abies pindrow*) Forest (2400m, a.s.l.) were chosen to examine the influence of terrain characteristics on forest structure and composition without the confounding effect of different climatic regimes. All three forest types were located in same geographical range and exhibit no apparent differences in structure without major topographic variation (Fig. 1). The climatic conditions of the sites are similar except for rainfall, which decrease as altitude increases, and snowfall accumulation, which increases with altitude (Table 1). Based on the amount and monthly pattern of precipitation (Fig. 2) and temperature (Fig. 3) the overall climate of the study area may be classified as *CWB* type by Koeppen's rating (1923) with an average frost free growing period of 204 days extending from April to October. Average annual precipitation for the area is 400 mm, with 65% falling as rain from May to August. Snow fall occurs during the winter months (December to march). The mean annual temperature is 15ºC, with an average daily minimum of – 4.3ºC in January to an average daily maximum of 30ºC in August. Climate shows variations due to variation in topography, altitude and aspect. The rainfall is on average higher in low altitude than in high altitude while temperature exhibit opposite trends (Table 1). In the study area there are certain dry inner valleys to which the monsoon does not penetrate results in the change to the dry temperate forests where snowmelt is enough to maintain the soil moisture during the summer month. Most of the trees and shrubs of the outer moist temperate forests do not extend to the inner dry valleys and ultimately overall vegetation become sufficiently different to describe dry and wet temperate forests separately. However, no sharp line can be drawn between the moist and dry temperate forest.

Table 1. Comparison of environmental factors among three forest types: Low level Blue Pine Forests (Lower Pine Forest), Mid *Cedrus deodara* Forests (Mid Cedrus Forest) and Upper *Abies pindrow* Forests (Upper Fir Forest), along altitudinal gradient.

Characteristics	Forest Types		
	Lower Pine Forest	Mid Cedrus Forest	Upper Fir Forest
Locality/site	Paprung	Kamal ben	Naran
Reserved Area (km²)	1605	1168	1087
Latitude	N 34° 37.011′	N 34° 42. 034′	N 34° 55.589′
Longitude	E 73° 18.311′	E 073° 31. 232′	E 73° 40. 306′
Site elevation (m a.s.l)	2000 -2200	2200- 2400	2400- 2700
Annual precipitation (mm)	1526	893	803
Wind speed (ms^{-1})	0.40	0.51	0.92
Main climatic influence	Moist Temperate	Moist Temperate	Dry Temperate
Mean winter snow accumulation (Cm)	182	243	610
Mean winter Temperature (˚C)	3.27	3.29	0.33
Average Summer Temperature (˚C)	19	12	10
Heat index (˚C)	25.8	24.5	24.3
% Relative Humidity(summer)	28.5- 37.69	35.8 – 47.50	45.50- 56
% Rock cover stoniness	≤ 25	25- 75	≥ 75
Underlying lithology	Lime stone	Quartz	Granite
Dominant tree species	*Pinus wallichiana*	*Cedrus deodara*	*Abies pindrow*
Common shrubs	*Berberis sp.*	*Parrotiopsis sp.*	*Artemisia sp.*

Tree Census

A comprehensive botanical survey of all the three forest types was conducted during 2011 – 2013. The forest inventory includes three forest types: Low Level Blue Pine Forest (Lower Pine Forest), Mid *Cedrus deodara* Forest (Mid Cedrus Forest) and Upper *Abies pindrow* Forest (Upper Fir Forest), two forest sites (The altitudinal difference between sites was not less than 100m) three topographic positions (low, mid, upper slopes at each site), eight stands (on each topographic position, Fig. 4). Tree data were collected from 144 stands of 10m² (Fig. 4).

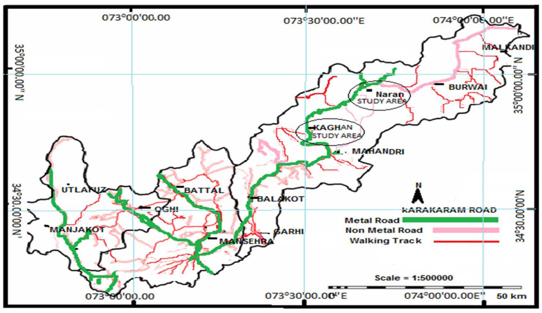


Fig. 1. Map showing the study sites (in circles) for Lower Western Himalayan Temperate forests (Low Level Blue Pine Forest and Mid *Cedrus deodara* Forest, Kaghan) and Upper West Himalayan Fir Forests (Upper *Abies pindrow* Forest, Naran), Pakistan.

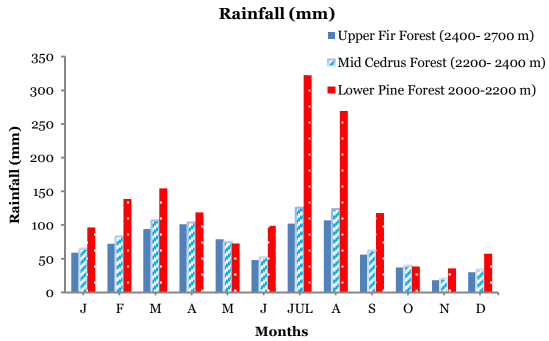


Fig. 2. Mean monthly rainfall distribution for three Forest types: Low level Blue Pine Forest (Lower Pine Forest), Mid *Cedrus deodara* Forest (Mid Cedrus Forest) and Upper *Abies pindrow* Forest (Upper Fir Forest) along altitudinal gradient (Data collected from Metrological Department Lahore, Pakistan).

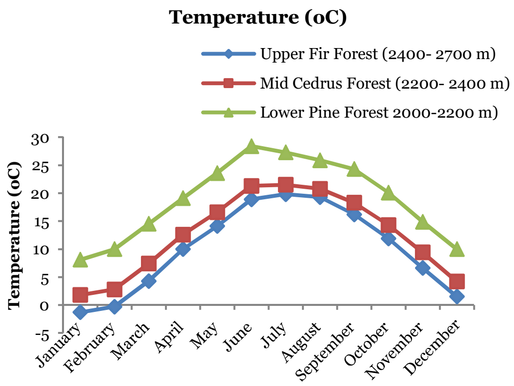
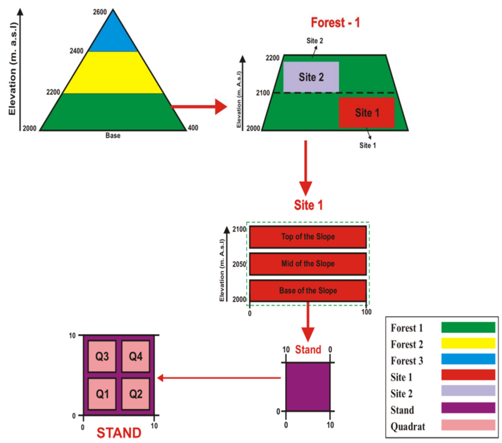


Fig. 3. Mean monthly temperature (◦C) for three Forest types: Low level Blue Pine Forest (Lower Pine Forest), Mid *Cedrus deodara* Forest (Mid Cedrus Forest) and Upper *Abies pindrow* Forest (Upper Fir Forest) along altitudinal gradient.

In each stands total number of trees were marked, counted and characterized to species level. Ordinal scales used for assessment of % rock cover, % litter cover and canopy openess. The canopy attributes were monitored for conifer species (*Pinus wallichiana, Cedrus deodara, Abies pindrow* and *Picea smithiana*) and broad-leaved species present in the sampling stands. The data obtained from broad-leaved species were pooled together and designated as 'other species' in the analyses instead of individual species. As the temperate forests consist of almost exclusively conifer species with small admixture of broad leaved species, it was justified to Poole the data for these species for smooth statistical analyses. In each stand 2-5 individuals of each species were selected based on qualitative good- vigor traits, such as canopy covered with green leaves, low frequency of dead branches, trunk covered with bark and low frequency of scars to monitor the canopy attributes. The mean values across the individuals present in a stand were used for further analyses. The canopy attributes data comprises of three forest types, two sites, three topographic positions, eight replicated stands and five species. Thus a total of 720 data bits were used in the analysis of variance.



Forest 1= Low Level Blue Pine Forest

Forest 2= Mid Cedrus deodara Forest

Forest 3= Upper Abies Pindrow Forest

Stand (10 x 10 m)

Quadrat (4 x 4 m)

Fig. 4. Showing the study sites and sampling scheme for collection of vegetation data from three forest types, two sites, eight stands and four quadrats.

Stem diameter to the nearest mm was recorded using tree caliper at height of 1.3m above ground level. Individuals with buttress or other stem irregularities at breast height were measured in diameter both at breast height and above buttress. Basal area was derived from *DBH* (Table 2) measurements following (Mueller-Dombois and Ellenberg, 1974). The height (H_t) of the marked tree (length from stump height to the tip of the leader), Bole height (H_b) (distance from the ground line to the base of the live crown) were determined using Clinometer (HB 443). Tree height (H_t) and basal area (BA) were used for calculating bole volume and certain other tree attributes (Table 2). Crown diameter (C_d) was measured with measuring tape. Crown length (C_l) was calculated as the difference between total height and the height to crown base using clinometer (Goff and Ottorini 1996). Crown volume (C_{rv}) and crown surface area (C_{rs}) were derived from crown length and crown diameter measurements (Aiba and Kohyama 1997). The importance value (IV) of a species is defined as the average of its relative density (*RD*), relative frequency (*RF*), and relative dominance *(Rd)*. The importance value of tree species was calculated as (Curtis and Mclntosh 1951; Cottam and Curtis 1956; Arbainsyah *et al.* 2014; Chai and Wang, 2016).

$$\text{Density (D)} = \frac{\text{Number of individual of species}}{\text{area of all sample units}}$$

$$\text{Relative density } (RD) = \frac{\text{Number of individual of species}}{\text{Density for all species}} \times 100\%$$

$$\text{Frequency } (F) = \frac{\text{Number of quadrats containing a certain species}}{\text{Total number of quadrats}}$$

$$\text{Relative Frequency } (RF) = \frac{\text{Frequency of a certain species}}{\text{Total number of species}} \times 100\%$$

$$\text{Dominance } (d) = \frac{\text{Basal area of a species}}{\text{Area of all sample units}}$$

$$\text{Relative Dominance } (Rd) = \frac{\text{Dominance of one species}}{\text{Dominance of all species}} \times 100\%$$

$$IV = \frac{(RD + RF + Rd)}{3}$$

Table 2. Tree parameters descriptions, mathematical notations and SI units.

Parameters	Description	Unit
Bole diameter at breast height (d.b.h)	d.b.h was measured at fixed stem heights: 1.3 m above ground line	Cm
Tree Basal area (BA)	Basal area was computed as the area of cross section of the tree at breast height: $BA = \pi * (D_{bh})^2 / (4*10000)$	$m^2\ ha^{-1}$
Tree Height (H_t)	Total tree height was defined as length from soil surface to the tip of the leader.	M
Bole Height (H_b)	Length from soil surface to the base of crown.	M
Bole Volume (V_b)	Bole volume was calculated by computing total tree height (H_t) and basal area (ba) using the following equation $V_b = 0.42 * ba * h$	m^3
Crown diameter (C_d)	Crown diameter was defined as an average of two perpendicular crown diameter measurements.	M
Crown length (C_l)	Crown length was calculated as the difference between total height and height to crown base (H_{bc}). Defined as the distance from the highest leaves to the lowest leaves on branches.	M
Crown Volume (C_{rv})	Crown volume was derived from crown diameter and crown length as: $\text{Crown volume} = \frac{\pi cdL}{12}$	m^3
Crown surface area (C_{rs})	Crown surface area was calculated as function of crown length (L) and crown diameter (Cd) by assuming that tree shape is a cone: $\text{Surface area} = \frac{\pi cd}{2} * \sqrt{L^2 + \left(\frac{cd}{2}\right)^2}$	m^2

Results

Altitudinal zonation in forest

The Himalayan temperate forest under consideration can be relatively simply subdivided on the bases of dominant species (Table 3). Among the conifers an altitudinal zonation was recognizable dominated successively by *Pinus wallichiana* (IV=28.43*), Cedrus deodara* (IV = 29.56) and *Abies pindrow* (IV=32.71).These forests were designated as (i) Upper fir forest (*Abies pindrow),* (ii) Mid Cedrus forest (*Cedrus deodara*) and (iii) Low-level blue pine forest (*Pinus wallichiana*) hereafter.

Table 3. Importance values for different tree species among three forest types: Low level Blue Pine Forest (Lower Pine Forests), Mid *Cedrus deodara* Forests (Mid Cedrus Forest) and Upper *Abies pindrow* Forests (Upper Fir Forests).

Species	Lower Pine Forests	Mid Cedrus Forests	Upper Fir Forests
Abies pindrow	17.96	18.16	32.71
Cedrus deodara	8.79	29.56	22.18
Pinus wallichiana	28.43	12.81	14.36
Picea smithiana	11.61	10.91	9.68
Aesculus indica	7.95	6.78	5.68
Acer caesium	7.97	7.26	5.17
Juglans regia	9.08	7.38	5.31
Populus ciliate	8.21	7.14	4.92

Analysis of variance (Table 5) showed significant differences in tree density among the forest types (F= 60.49, P< 0.001) and among species (F=586.98, P <0.001).

Tree density exhibited a steady decline with increasing altitude (Table 4). The highest density was recorded in low blue pine forest, intermediate in mid Cedrus forest and the lowest tree density was recorded in upper fir forest (Table 4). Among the component species *Abies pindrow* showed significantly higher density (102.42) followed by *Pinus wallichiana* (83.46) and *Cedrus deodara* (80.67). Broad- leaved species had considerably low density (14.04) in these forests (Table 6). The first order interaction between forest type and species was significant (F= 337.14, P=0.001, Table 4), an indication that the density of the component species changed from one forest to another. The density of *Pinus wallichiana* showed a drastic decrease with increase in elevation from Low level blue pine forest (2000-2200m a.s.l.) to mid Cedrus forest 2200–2400m a.s.l. On the other hand, the density of *Cedrus deodara* exhibited a significant increase and approached it maximum in *Cedrus deodara* Forest, followed by a significant decrease in density by approaching the upper fir forest (Fig. 5). Contrary to the previous species, *Abies pindrow* from the elevation of low level blue pine forest onwards exhibited a continuous increase to the value of 150 individuals, hac^{-1} at the timberline forest (2700m. a.s.l.). The density of Broad-leaved species and *Picea smithiana* remain consistently low and often exhibited insignificant changes from one forest type to the other (Fig. 5).

Table 4. Comparisons of forest attributes between three forest types: Low level Blue Pine Forests (Lower Pine Forests); Mid *Cedrus deodara* Forests (Cedrus Forests); Upper *Abies pindrow* Forests (Fir Forests). Values are means across, five species, three topographic positions (Plot elevation) and eight forest stand (plots). Values that are not significantly different at P <0.05 have the same superscript letters.

Variables	Lower Pine Forest (2000-2200)	Mid Cedrus Forest (2200-2400)	Upper Fir Forest (2400-2700)	F-value
d.b.h (cm)	39.56^{a}	40.23^{b}	45.67^{c}	223.13^{***}
Basal area (m²/ha)	0.12^{a}	0.13^{b}	0.17^{c}	231.88^{***}
Tree height (m)	27.72^{c}	25.77^{b}	23.97^{a}	153.42^{***}
Bole height (m)	18.76^{b}	17.87^{b}	16.05^{a}	60.26^{***}
Bole volume (m³)	2.27^{a}	2.33^{b}	2.67^{c}	44.65^{***}
Crown length (m)	8.96^{b}	8.14^{b}	7.92^{a}	20.05^{***}
Crown diameter (m)	8.13^{b}	7.92^{a}	8.03^{ab}	21.32^{***}
Crown volume (m³)	154.63^{b}	134.58^{a}	136.11^{a}	36.10^{***}
Crown surface area (m²)	178.97^{b}	163.30^{a}	164.58^{ab}	44.53^{***}
Tree density ha^{-1}	333^{c}	318^{b}	286^{a}	60.49^{***}

*P <0.05, **P<0.01, ***P<0.001.

Table 5. Result of 2 x 2 ANOVAS for the different canopy attributes of three Himalayan Moist Temperate Forests: Low Level Blue Pine Forests (Lower Pine Forests), Mid *Cedrus deodara* Forests (Mid Cedrus Forests) and Upper *Abies pindrow* Forests (Upper Fir Forests). The *F* –values are presented for main effects (Forest type and Site elevation) and their interaction with their level of significance indicated.

Parameters	DF	D.b.h (cm)	BA (m^2/ha)	Tree Height (m)	Bole Height (m)	Bole volume (m^3)	Crown Length (m)	Crown Surface Area (m^2)	Crown Diameter (m)	Crown Volume (m^3)	Tree Density hac^{-1}
Forest type (F)	2	204.36***	212.49***	144.58***	144.58***	40.69***	20.92***	39.05***	19.74***	36.10***	60.49***
Site elevation(S)	1	12.45***	12.39***	26.61***	26.61***	7.45**	80.74***	24.18***	1.64	38.10***	7.52**
Plot elevation (TP)	2	0.49	0.23	1.48	1.48	0.68	1.62	4.40*	2.73*	4.16*	16.09***
Species (SP)	4	12.65***	13.79***	44.95***	44.95***	24.64***	5.52***	9.07***	21.04***	7.24***	586.98***
Stand elevation (ST)	7	4.75***	4.57***	4.51***	4.51***	5.61***	0.69	2.40*	1.83*	2.53*	6.31***
F x S	2	3.16*	3.78*	0.66	0.66	5.46**	1.53	8.72***	23.41***	3.76*	19.88***
F x TP	4	1.19	1.00	1.62	1.62	1.54	1.67	0.92	2.30*	1.03*	7.13***
F x SP	8	9.88***	10.31**	14.24***	14.24***	14.67***	9.29***	9.43***	15.35***	10.59***	337.14***
F x ST	14	0.71	0.68	1.92*	1.92*	0.60	1.09	0.93	0.64	0.95NS	0.66
S x TP	2	1.23	1.15	5.81**	5.81**	0.79	2.56*	7.03**	4.75**	7.53**	1.45
S x SP	4	2.04*	1.80	3.68**	3.68**	3.35*	29.30***	6.73***	11.24***	12.26***	5.96***
TP x SP	8	0.88	0.85	2.27*	2.27*	0.88	1.48	2.18*	1.80*	2.34*	1.02
TP x ST	14	0.68	0.64	0.82	0.82	0.41	0.94	1.02	0.65	1.28	6.40***
F x S x TP	4	2.09*	1.93	1.27	1.27	0.98	1.51	6.18***	4.43**	6.51**	2.40**
Error	642										

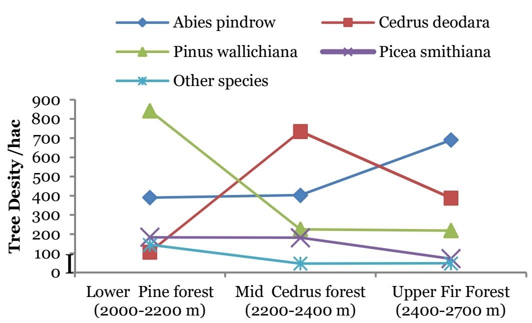


Fig. 5. Mean tree density of five species among three forest types along altitudinal gradients. The values are means across two sites, three topographic position and eight stands. Vertical bar indicates LSD ($P < 0.05$).

Canopy Attributes

Analysis of variance for all the canopy attributes listed in table 5 gave highly significant responses for all the main effects and most of the interactions. The highly significant main effects suggest that each of the separate factors (forest type, site elevation, plot elevation, stand elevation and species) was significantly strong that its effect was still apparent when averaged over other factors in the study. The significant interactions, however, mean that the actual pattern of canopy attributes responses to each factor depends on the level of the other factors. In particular, the significant two-way interaction between forest type and species indicates the canopy responses of the component forest species (*Abies pindrow, Cedrus deodara, Pinus wallichiana, Picea smithiana, Aesculus indica, Acer caesium, Juglans regia* and *Populus ciliata*) changes with the forest type as is strikingly apparent from Figs. 6- 14.

Tree Height (m)

Analysis of variance (Table 5) demonstrated significant differences in height among the forest types (F= 144.58, P<0.001) and among species (F=44.95 P< 0.001). Tree height reduced with increase in altitude from Low level blue Pine forest to Upper Fir forest. Average values of tree height can be arranged in the order of Lower Pine Forest > Mid Cedrus Forest > Upper Fir Forest (Table 4). Among species *Cedrus deodara, Pinus wallichiana, Picea smithiana* and *Abies pindrow* were significantly different in height from the rest (Table 6). The interaction between forest type and species was significant (F = 14.24, P > 0.001, Table 5), an indication that pattern and magnitude of response to altitude (forest type) differed between the species. The results depicted in Fig. 6, shows that all the species demonstrated a linear mode of decline in height as the elevation progressed from Low level blue Pine forests to Upper Fir Forests but they differed in degree of decline at different elevations along the gradient. Tree height in *Pinus wallichiana, Picea smithiana* and *Abies pindrow* exhibited a steady decline, as compared to that of *Cedrus* *deodara* and associated broadleaved species that exhibited relatively minor changes in height along the altitudinal gradient from 2000m – 2700m (Fig. 6). Consequently, the inter-specific differences in tree height realized at low elevations (2000-2200m, Table 4) became smaller as the altitude increased from Low level blue Pine forest to Upper Fir forest. As a result, all the species ultimately exhibited uniform height in Upper Fir forest (2700m).

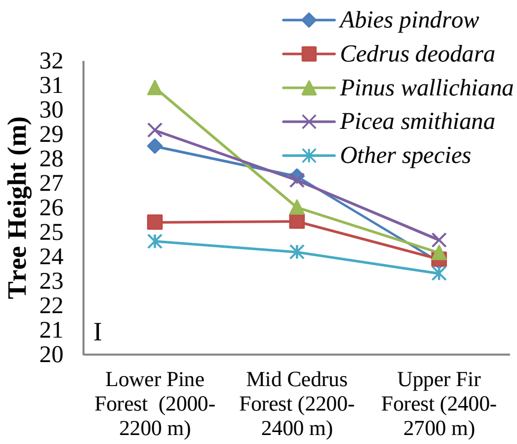


Fig. 6. Mean Tree height of five species among three forest types along altitudinal gradient. The values are means across two sites, three topographic position and eight stands.

Bole Height (m)

Like tree height, bole height also decreased significantly with increasing altitude from lower blue pine forest to upper fir forest (Table 4). Analysis of variance (Table 5) indicates that a high proportion of the variance is accounted for by the altitudinal gradient present among the forests. Further, the interaction between forest types and site elevation show clearly the importance of altitude in determining the bole height. The high proportion of variance (F = 144.58, P > 0.001) encountered for forest type (elevation at gradient scale) alone indicates its large effect on the bole height than any other factors included in this study. The two-way interaction between forest type and species was significant (F = 14. 24, P > 0.001), indicated that bole height measurements of the five species change along with altitudinal gradient, as is strikingly apparent from Fig. 7. Although bole height tends to decrease with altitude, the responses differed between the species. Comparing species, the bole height of *Cedrus deodara* was significantly lower than *Abies pindrow* and *Pinus wallichiana* at lower forests, but this difference between the species did not persist in the upper forests. On the other hand, Broad leaved species were able to maintain their high values of bole height along the altitudinal gradient (Fig. 7). Although bole height was quite variable within the species along the altitudinal gradient (2000 -2700 m) the mean values of bole height of *Abies pindrow* and broad leaved species was higher than the remaining conifer species which did not differ between themselves (Table 6).

Table 6. Comparison of tree species attributes of three forest types. Values are means across three forest types, two sites, three topographic positions, eight forest stands and five species. Values that are not significantly different at P < 0.05 have the same superscript letter.

Variables	Abies pindrow	Cedrus deodara	Pinus wallichiana	Picea smithiana	Broad leaved species	F- value
·*D.b.h. (cm)/ hac*	41.82^{b}	43.08^{c}	41.83^{b}	42.26^{bc}	40.13^{a}	13.68***
··*BA (m^2/ hac)*	0.14^{ab}	0.15^{b}	0.14^{ab}	0.14^{ab}	0.13^{a}	14.91***
Tree Height (m)	26.54^{c}	24.92^{b}	27.03^{c}	26.99^{c}	24.04^{a}	48.49***
Bole Height (m)	18.40^{cd}	17.39^{ab}	17.87^{bc}	17.13^{a}	18.71^{d}	24.73***
Bole Volume (m^3)	2.47^{b}	2.53^{b}	2.43^{b}	2.47^{b}	2.04^{a}	26.47***
Crown length (m)	8.19^{ab}	7.95a	8.58^{bc}	8.43^{bc}	8.82^{c}	6.59***
Crown diameter (m)	8.29^{b}	7.53^{a}	8.31^{b}	8.31^{b}	7.68^{a}	22.93***
Crown volume (m^3)	147.16^{c}	120.48^{a}	154.14^{c}	155.38^{c}	135.24^{b}	7.24***
Crown surface area (m^2)	176.14^{c}	149.20^{a}	180.77^{c}	178.41^{c}	162.96^{b}	10.65***
Tree Density hac^{-1}	102.42^{d}	80.67^{c}	83.46^{c}	25.63^{b}	14.04^{a}	1037.05***

**P* <0.05, ***P*<0.01, ****P*<0.001;

·D.b.h = Diameter at breast height, ··BA = Basal area

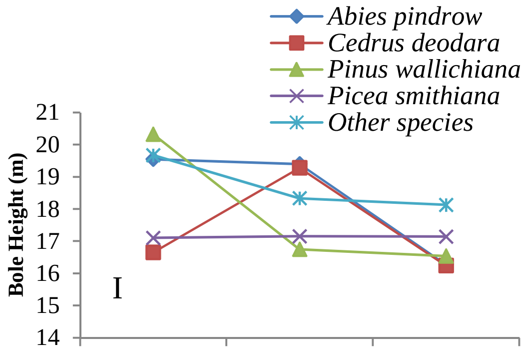


Fig. 7. Mean Bole height of five species among three forest types along altitudinal gradients. The values are means across two sites, three topographic position and eight stands. Vertical bar indicates LSD ($P < 0.05$).

Stem Diameter (DBH, cm) and Basal area (BA, m²)

Stem diameter was significantly (P<0.001) differed between the three forest types regardless of species. Averaged over the species sites and stands, *DBH* was the highest in upper fir forest; intermediate in mid deodar forest and the lowest in low level blue pine forest. The results suggested that variations in *DBH* were mostly determined by forest elevation rather than species main effect (Table 5). Although, stem diameter of the component species changed from one forest type to the other (Fig. 8) the magnitude of increase differed between the component species (Fig. 8), the forest type x species interaction being significant at P <0.001 (Table 4). The *DBH* of the five species were not affected by initial increase in forest elevation from 2000-2400m). As the elevation progressed upward, the *DBH* of all the species increased significantly. *Abies pindrow* displayed a dramatic increase compared to the *DBH* in broad-leaved species across the elevation gradient. Species differences in *DBH* also existed (F= 12.665, P<0.001): *Cedrus deodara* exhibited significantly higher *DBH* than *Abies pindrow, Pinus wallichiana* and *Picea smithiana,* which did not differ between themselves (Table 6). Among the component species, Broad-Leaved had the lowest value of *DBH* (Table 6).

Like *DBH,* basal area (*BA*, m²) differed significantly (F = 231.88, P < 0.001) among the three forest types. Basal area was high in upper fir forest (0.17m²), intermediate in mid deodar forest (0.13m²) and low in low-level blue pine forest (0.12m²). A significant interaction between forest type and species for basal area indicated that the pattern of changes across the forest types for the five species was different. The trends depicted in Fig. 9, Show that all the component species underwent a steady rise in basal area with increasing forest elevation above 2400 m. The forest to forest changes in basal area were largely the mirror image of the similar changes in *DBH*. For basal area, species differences were observed (Table 5). *Cedrus deodara* had significantly higher basal area (m²) than all the other species which did not differ between themselves (Table 6).

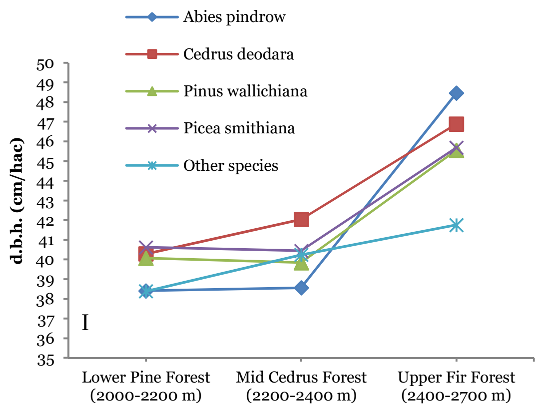


Fig. 8. Mean d.b.h. of five species among three forest types along altitudinal gradients. The values are means across two sites, three topographic positions and eight stands. Vertical bar indicates LSD ($P < 0.05$).

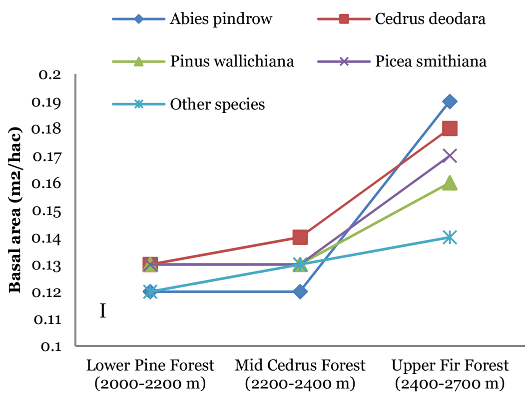


Fig. 9. Mean Basal area of five species among three forest types along altitudinal gradients. The values are means across two sites, three topographic positions and eight stands. Vertical bar indicates LSD ($P < 0.05$).

Bole Volume (m3)

Three forest types located along the altitudinal gradient differed significantly in tree bole volume (*F* = 7.45, *P* <0.01, Table 5), an indication of influence of altitude on this parameter. Bole volume exhibited a steady increase with increasing altitude. Consequently, low level blue Pine forest showed lower bole volume than that of mid Cedrus and upper fir forest (Table 4).

For bole volume, a strong species effect was found. Broad leaved species showed significantly (*P*< 0.001) lower in bole volume compared with all conifer species which differed little between themselves. Again, there were species differences in response to altitudinal gradient (among the forests) as the interaction between forest type and species is significant (Table 5, Fig. 10). *Cedrus deodara* exhibited steady increase in bole volume with increase in altitude from low level pine forest to upper fir forest (2000 to 2700m). This altitudinal trend in bole volume is not true for other conifer species (Fig. 10). *Pinus wallichiana* and *Picea smithiana* showed a significant decline in bole volume in mid Cedrus forest which reverted to the lower pine forest by further increase in altitude at the level of upper fir forest. Consequently, in upper forests no significant difference in bole volume was observed among the conifer species. At this altitude the bole volume of broadleaved species declined and approached to the level not significantly different from that of lower pine forest.

Crown Length (m)

Crown length decreased with increase in altitude from lower pine forest to upper fir forest and can be arranged in the order of lower pine forest > mid *Cedrus* forest > upper fir forest. From Fig. 11 can be seen that crown length of *Cedrus deodara*, *Abies pindrow*, and broadleaved species declined to a minimum with the increase in altitude. *Picea smithiana* exhibited an initial decline in mid *Cedrus* forest, followed by an increase in upper fir forest. Contrary to the *Picea smithiana*, *Pinus wallichiana* showed a significant increase in crown length and shifted apart from all other species in mid *Cedrus* forest. On progressive increase in altitude and comparison made with other species, *Pinus wallichiana* showed similar crown length with all other species in upper fir forest except *Picea smithiana* which showed maximum crown length in these forests. The results depicted in Fig. 11 showed that species differences appeared at one altitude became masked at the other. This altitude dependent pattern of crown length of different species were responsible for the occurrence of forest type x species interaction significant (*F* = 9.29, *P* <0.001, Table 5). Apart from these altitudinal changes, the crown length was the lowest in *Cedrus deodara*, intermediate in *Abies pindrow* while, the highest crown length was recorded for *Pinus wallichiana*, *Picea smithiana*, and broad leaved species which differ little from one another.

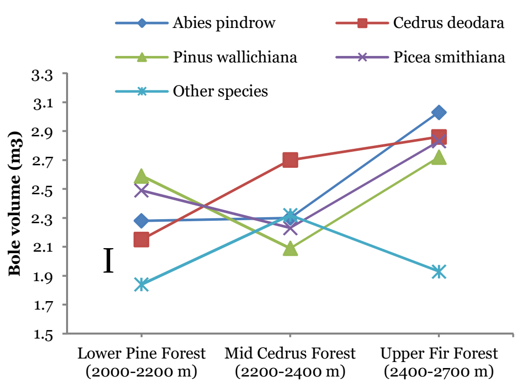


Fig. 10. Mean Bole volume of five species among three forest types along altitudinal gradient. The values are means across two sites, three topographic position and eight stands. Vertical bar indicates LSD (*P* < 0.05).

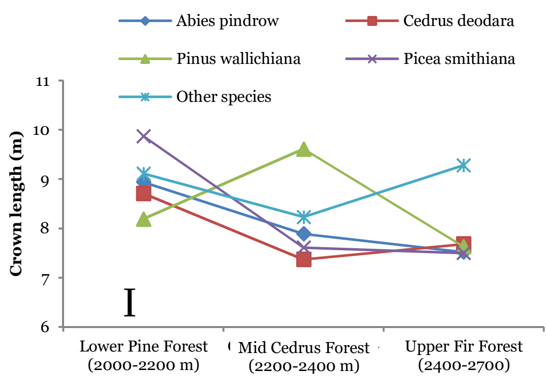


Fig. 11. Mean Crown length of five species among three forest types along altitudinal gradient. The values are means across two sites, three topographic position and eight stands. Vertical bar indicates LSD (*P* < 0.05).

Crown Surface Area (C_{rs}, m²)

The results of ANOVA (Table 5) showed that altitude at gradient scale (forest type) influenced the crown surface area significantly. Lower pine forest exhibited the higher value of Cr_s than either the mid *Cedrus* or upper fir forest which did not differ between them (Table 4). There were significant differences among the species for Cr_s which can be ranked in the order of *Pinus wallichiana* > *Abies pindrow* = *Picea smithiana* > Broad leaved > *Cedrus deodara* (Table 6). Beside the main factors, their interactions were also significant in the overall analysis of variance. Despite the complexity of the interactions, the ANOVA demonstrated that the main determinant of interspecific variations in Cr_s is the variation in elevation at gradient scale (among forest). The results depicted in Fig. 12 shows that *Cedrus deodara* exhibited a significant drop in Cr_s by increase in elevation from lower pine forest to mid *Cedrus* forest. This decline in Cr_s was reversed when elevation progressed further from mid *Cedrus* forest to upper fir forest. The altitudinal profile of crown surface area displayed by *Cedrus deodara* was not consistent to other species which showed little often insignificant changes in *Crs* across the altitudinal gradient.

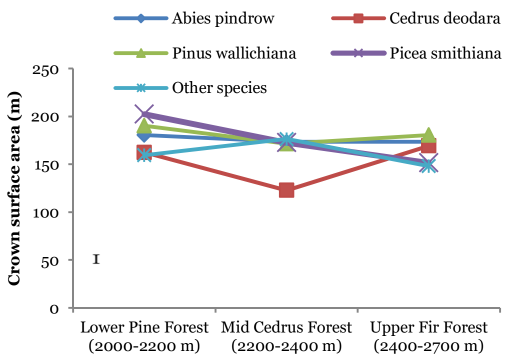


Fig. 12. Mean Crown surface area of five species among three forest types along altitudinal gradient. The values are means across two sites, three topographic position and eight stands. Vertical bar indicates LSD ($P < 0.05$).

Crown Diameter (m)

Mid *Cedrus* forests had significantly lower crown diameter than either or the upper fir forests and Lower Pine Forests which did not differ between themselves. These differences in crown diameter were species specific as the interaction between species and forest types was significant ($F = 15.35$, $P > 0.001$, Table 5) in overall analysis of variance. *Cedrus deodara* exhibited maximum crown diameter in Upper Fir Forest while, *Abies pindrow, Picea smithiana* and *Pinus wallichiana* in Lower Pine forests. Broad leaved species showed maximum crown diameter in Mid-*Cedrus* Forest (Fig. 13). Among the conifer species, *Picea smithiana* showed a steady decline in crown diameter with the increase in altitude as one move from Low level blue pine forest to upper fir forest. These trends in crown diameter were not consistent with that of remaining species. Similar comments may be made with broad leaved species in which crown diameter exhibited significant rise as it approached the Mid-*Cedrus* forests, followed by similar decline as the altitude increased further towards the upper fir forests. Averaged across the forest type, sites, plots and stands, *Pinus wallichiana* and *Picea smithiana* showed the highest value, followed by *Abies pindrow* (Table 6). Among the conifer species, *Cedrus deodara* exhibited minimum value of crown diameter even lesser than broad leaved species. The main effect of other variables such as site, topographic position of the plot and sampling stands were not significant. At plot level variations in elevation all the species reacted similarly as the species x topographic position was not significant (Table 5).

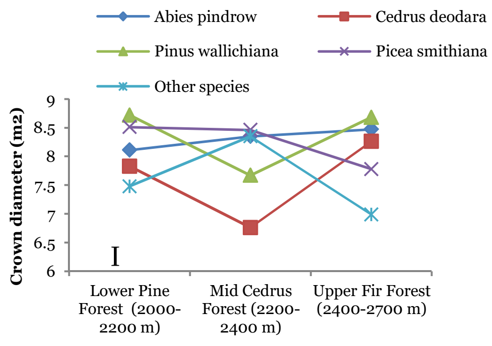


Fig. 13. Mean Crown diameter of five species among three forest types along altitudinal gradient. The values are means across two sites, three topographic position and eight stands. Vertical bar indicates LSD ($P < 0.05$).

Crown Volume (m³)

The values of variance indicate that altitude at gradient scale (Forest type) influence the crown volume (Cr_v) significantly (Table 5). Low level blue Pine Forest showed the higher values of crown volume (Cr_v) than either the mid *Cedrus*, upper fir forest which did not differ between them (Table 4). Although the complexity of the interactions, the ANOVA demonstrated that the main determinant of interspecific variations in Cr_v is the variation in elevation at gradient scale (Large scale/ Forest type). The results depicted in Fig. 14 shows that *Cedrus deodara* exhibited a significant drop in Cr_v by increase in elevation from Lower Pine Forest to Mid Cedrus Forest. This decline in Cr_v was reserved when elevation progressed further from Mid Cedrus Forest to Upper Fir Forests (Fig. 14).

Forest-environment relationships

The results demonstrated a significant association between landscape level patterns of environmental heterogeneity and distribution of forest types and their attributes across the landscape (Table 7). Altitude and its associated climatic factors such as rainfall, temperature, and snow fall accumulation seem to be operative in shaping the forest structure and composition. Most of the canopy parameters showed significant correlations with altitude, rainfall and temperature and snow depth (Table 7). It is difficult to assess the relative importance of these factors in comparison with altitude, but had strong correlation with elevation suggested that some combine effect is important which affect forest structure and canopy attributes.

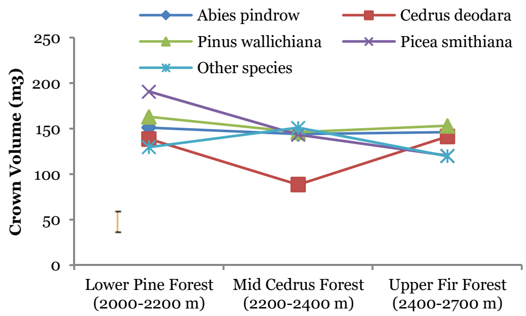


Fig. 14. Mean Crown volume of five species among three forest types along altitudinal gradient. The values are means across two sites, three topographic position and eight stands. Vertical bar indicates LSD ($P < 0.05$).

Table 7. Pearson correlation coefficient between canopy attributes and geo-climatic factors for the three forest types located along the altitudinal range 2000 to 2700 m. (a.s.l).

	Altitude	DBH (cm)	BA (m2)	Tree Ht	Crow l	Bole ht	Bole vol.	Crow dia.	Crow Vol.	Crow Surf	RH%	HI °C	Mean temp	Rain fall	Winter sno.	%Rock cov.	Wind spe.	Tree dens.
DBH (cm)	-0.096																	
	0.255																	
BA (m2)	-0.085	0.994																
	0.312	0.000																
Tree Height	-0.144	0.051	0.051															
	0.086	0.547	0.541															
Crown length	0.151	-0.095	-0.120	0.396														
	0.072	0.257	0.224	0.000														
Bole height	-0.233	0.103	0.107	0.884	-0.078													
	0.005	0.218	0.200	0.000	0.351													
Bole volume	-0.183	0.785	0.788	0.576	-0.104	0.678												
	0.029	0.000	0.000	0.000	0.214	0.000												
Crown dia	0.048	0.595	0.602	0.391	-0.118	0.159	0.746											
	0.568	0.000	0.000	0.000	0.159	0.000	0.000											
Crown Volume	0.100	0.393	0.396	0.609	0.642	0.334	0.518	0.671										
	0.233	0.000	0.000	0.000	0.000	0.000	0.000	0.000										
Crown surfac	0.13	0.428	0.430	0.591	0.581	0.346	0.548	0.738	0.99									
	0.121	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000									
RH%	0.294	0.112	0.115	-0.141	0.078	-0.193	0.005	-0.045	0.016	0.019								
	0.000	0.181	0.169	0.091	0.350	0.020	0.957	0.593	0.847	0.824								
HI °C	-0.276	-0.19	-0.185	0.223	-0.082	0.284	0.002	0.018	-0.042	-0.044	-0.900							
	0.001	0.023	0.026	0.007	0.327	0.001	0.982	0.830	0.621	0.602	0.000							
Mean temp	-0.351	-0.173	-0.171	0.209	-0.118	0.287	0.014	0.018	-0.065	-0.068	-0.904	0.979						
	0.000	0.038	0.040	0.012	0.160	0.000	0.866	0.83	0.438	0.42	0.000	0.000						
Rain fall	-0.824	0.168	0.165	0.45	-0.092	0.535	0.429	0.202	0.138	0.118	-0.406	0.436	0.482					
	0.000	0.044	0.049	0.000	0.272	0.000	0.000	0.012	0.100	0.158	0.000	0.000	0.000					
Winter snow	0.728	-0.2	-0.197	-0.505	0.056	-0.576	-0.483	-0.271	-0.211	-0.193	0.354	-0.395	-0.433	-0.120	-0.983			
	0.000	0.016	0.018	0.000	0.508	0.000	0.000	0.001	0.011	0.001	0.000	0.000	0.000	0.151	0.000			
%Rock cover	0.909	0.002	0.008	-0.108	0.075	-0.156	-0.062	0.088	0.088	0.114	0.418	-0.339	-0.402	-0.267	-0.669	0.538		
	0.000	0.984	0.926	0.201	0.370	0.063	0.643	0.295	0.299	0.117	0.000	0.000	0.000	0.001	0.000	0.000		
Wind speed	0.912	0.007	0.018	-0.108	0.075	-0.156	-0.056	0.067	0.088	0.114	0.418	-0.339	-0.402	-0.267	-0.669	0.538	0.346	
	0.000	0.698	0.999	0.217	0.37	0.146	0.563	0.217	0.299	0.117	0.000	0.000	0.000	0.000	0.000	0.000	0.004	
Tree density	-0.214	0.005	0.012	0.195	0.04	0.192	0.114	0.024	0.048	0.046	-0.269	0.317	0.305	0.071	0.265	-0.240	-0.243	-0.254
	0.01	0.955	0.955	0.019	0.632	0.021	0.174	0.778	0.567	0.580	0.001	0.000	0.000	0.000	0.001	0.004	0.000	0.002

Discussion

General Pattern

In geological terms the Himalaya are a recent creation, thereby great variation in climate and habitat to be found here (Givnish, 1999; Willig *et al.* 2003; Gairola *et al.* 2008). Altitude is the most important of the various factors which combine to create contrast in habitat, climate and vegetation (Dasti *et al.* 2007; Wazir *et al.* 2008; Saima *et al.* 2009). The areas chosen for study were those where conifers were abundant, so some basic consistency among such forest sites would be expected. However, an initial objective of the present investigation was to select a series of contrasting study sites along elevation gradient. This aim was certainly met; the three forest sites were significantly different for majority of environmental measure used (Table 1). In the study area canopy attributes and growth parameters such as tree height, diameter at breast height and crown diameter of tree species change with altitude from Lower Blue Pine to Subalpine mixed coniferous forests. The upper distribution limit of subalpine forest is timberline. We observed altitudinal changes in forest structure from 2000m. a.s.l to 2700 (timberline). The temperature decreased with increasing altitude. Rainfall followed the same altitudinal sequence while the opposite trends were noted for snow accumulation. This pattern of climatic changes are common in uplands Himalaya (Garten *et al.* 1999; Hontoria *et al.* 1999; Quideau *et al.* 2001; Dai and Huang, 2005) and are considered important in determining the variation in forest structure, composition and function at gradient scale. Generally, wind velocity increases with altitude (Araki, 1995; Baker and Weisberg 1995). Strong winds in winter often cause mechanical damage of trees at high altitudes by snow abrasion due to wind-blown ice crystals; this damage causes winter desiccation (Hadley and Smith, 1983, 1986). Trunks and branches are also often broken by snow pressure (Seki *et al.* 2002). Thus, not only temperature, but also strong winds and snow are important for timberline formation. Temperature is the most obvious factor of climate. It can be broadly related to altitude giving a rough differentiation among the forest types (Champion and Seth, 1968). An upper forest zone with lower temperature, low rainfall, more snow, strong wind and greater run-off, can be easily distinguished. It differs from the main occurrence chiefly by the predominance of *Abies pindrow* among the conifers and relatively infrequent *Cedrus deodara*. It is evident that one of the factors determining the distribution of deodar forests is their avoidance of regions with heavy summer rainfall, and their good development where rainfall is relatively low but there is adequate snowfall. Thereby in the study area, Deodar Forests occupy mid altitudinal ranges with intermediate values of temperature and rainfall and ample snow melt. The lower *Pinus wallichiana* zone characterized by having ample rainfall, low run-off, high temperature and ample supply of nutrients relative to that of upper *Abies pindrow* forests. These results suggested that despite possessing many similarities the three forests are easily identifiable and show distinctive spatial structure, with many segregating attributes along the altitudinal gradient. Among the conifers dominated successively by *Pinus wallichiana, Cedrus deodara* and *Abies pindrow* with *Picea smithiana and* this classification is adopted here for further discussion and characterization of these forest types. This stresses the importance of topographic preference of tree species and may reflect differences in using resources.

Species assemblage

Despite possessing distinctive habitats, the three forests show many similarities in composition and structure. In all the three forest types number of dominant species is small and all consist of mixture of evergreen *Pinus wallichiana*, *Cedrus deodara*, *Abies pindrow* and *Picea smithiana* which make up the largest proportion of the forests under investigation. All these species are capable of attaining good height, very considerable girth and cover north slopes with little admixture of broadleaved trees. Probably the conifer species emerged as functional group with broad realized tolerance for all of the environmental variables measured. All the species appear to be resilient to variety of disturbances. This result supports the view that certain species may be ecological generalists for numerous environmental parameters.

Although the coexisting conifer species have a similar ecology but they differ in spatial pattern and thus correspond the theory of niche separation, which states that coexisting species exhibit contrasting structural, phonological or physiological characteristics that allow them to partition resources among themselves on spatial and temporal basis (Grime, 1974; Kemp and Williams, 1980). Comparisons of relative Importance Values showed that *Abies pindrow* achieved maximum dominance at high altitudes. *Pinus wallichiana* dominate the lower slopes whereas *Cedrus deodara* showed strong spatial segregation and dominate the mid altitudinal ranges. *Picea smithiana* showed little overall trend, but may be consistent from top to bottom. These results suggested that altitude and rainfall are the factors of prime importance in determining the type of the forest and community composition. Climatological data is being too inadequate for closer correlation.

The pattern of dominance by particular plant species is consistent with the notion that different species are adapted to different ecological conditions (Whitmore, 1984, Terborgh *et al.* 1996). The staggered elevational distribution of dominant tree species is consistent with the individualistic hypothesis (Gleason, 1917) and with the fact that such ecological dominants differ in environmental tolerance and resource requirements and are considered most important competitors, and thus among the most important determinants of each other's distribution (Whittaker, 1972). The ability of the species to survive, compete and reproduce successfully in different environments, resulting in each species having its own distinctive distribution. These characteristics of species affect fitness and are subject to evolution by natural selection.

Canopy attributes

Large differences in canopy attributes between the coexisting tree species were observed. These variations were many folds greater at gradient scale than that at small scale topographic variations as indicated by the variance ratio (Table 5). These results suggested that at local scale tree attributes change little and even did not change with substantial altitudinal variations within the forest particularly where the altitudinal interval is not > 100m). Having shown that spatial variations at gradient scale are more important in explaining differences in canopy attributes than at local scale, a further analysis of canopy attributes at gradient scale is imperative. The results (Table 4) showed that certain trade-offs in canopy attributes were existed. Recent models based on field data for temperate forests suggested that differences exist in canopy parameters among coexisting species and that trade-offs in canopy attributes can promote species coexistence (Kohyama, 1993) or can predict species composition (Pacala *et al.* 1993; Kobe *et al.* 1995). Several traits were also related to one another; plants that had overall high stature, had also high crown area but relatively small girth. Thus there were clear eco-physiological differences between those plant species that exhibited high crown area or high stature and those with short stature and low crown area. The close relationship we found between several of the traits we measured at least partially supports the conclusion of Reich *et al.* (1992) that co-variation in several interlinked traits provided useful conceptual link between processes at whole plant scales, and ecosystem level scale. The suit of canopy attributes we measured for each species thus provided suitable gradient across from which biotic interactions and ecosystem-level properties can be evaluated. The inter-specific differences in tree height, girth and crown parameters have important ecological implications. The advantage, of large size and greater canopy area seems clear. Such a plant has the opportunity to acquire a large share of limiting resources such as nutrients and light than small statured trees with smaller crown area (Grime, 1979).

The results depicted in Table 5 show that almost all the canopy attributes included in the present investigation gave highly significant response for all the main effects and their interactions. The highly significant main effects suggest that each of the separate factors (species, forest elevation, site elevation, and plot elevation) was sufficiently strong that its effect was still apparent when averaged over other factors in the study. Among the main factors, large scale variations in elevation (forest elevation) influenced the canopy attributes greater than at small scale topographic variations (plot elevation).

The significant interactions, however, mean that the actual pattern of tree responses to each factor depends on the level of other factors. In particular, the significant interaction between forest elevation and species mean that the species differences appeared at one elevation and disappeared at the other along elevation gradient (Table 5). It means that tree attributes are highly variable within a species along the altitudinal gradient. It would thus appear that the tree architecture is a complex function of species (genetic) and habitats that vary from lower canopy forest to subalpine timberline forests. These results have potentially important consequences for ecologists interested in the identification of genotypes with contrasting attributes.

All the species growing in Low Level Blue Pine Forest have greater height, greater crown surface area and lower values for d.b.h. and basal area than the forests around the mountain summit. In these forests the advantage of greater height and greater crown area seems clear. Such plants have the opportunity to acquire a large share of limited resources like light and nutrients than short statured plants with limited crown area such as *Cedrus deodara*. If these relationships are true then *Pinus wallichiana* may be considered as an important ecological competitor. The dominance of *Pinus wallichiana* in these forests (Table 3) confirms our assumptions.

The results (Table 4) suggested that plant height and crown diameter decreased while, diameter at breast height showed significant trends of increase with increasing altitude. These trends are true for all the conifer species although, the magnitude of increase or decrease was species specific. These results are consistent with observations that trees become stunted, have more open canopies at higher altitudes and invest more in growth in diameter as compared with the forests at lower altitude (Takashi *et al.* 2012). These structural alterations are linked with physiology and correspond to the severe environment in terms of low air and soil temperature, low rainfall and high snow accumulation, low nutrients and poor resource availability in the upper mountain forests.

There are several reasons why this combination of traits may be helpful to the ecological success of species in Upper Fir Forest. First, the correlated canopy attributes may be regarded as adaptive traits that have been modulated by natural selection to maximize fitness to the stressful environment (Kelly, 1992; Kelly and Levin, 1997). Secondly, coping with environmental stress involve reduction in growth process (production of new leaves and buds) as available energy is channeled into stress resisting processes (McCree, 1986) or to some extent the maintenance process such as repair of damaged tissues caused by low temperature and snowy winds. As the Environmental conditions became gradually severe with increasing altitude, the rate of increase in maintenance cost increased with elevation. As a consequence a steady decrease in trunk height has occurred with increasing elevation. However, the magnitude of decrease was specie specific reflecting the relative tolerance to cope with stress and ultimately survival (Messaoud *et al.* 2007; Takashi *et al.* 2012; Kessler, *et al.* 2014).

The data depicted in Fig. 6 show the differences in tree height between the four common conifer species. Plant height in *Abies pindrow*, *Pinus wallichiana*, *and Picea smithiana* showed a gradual decrease with increasing elevation, while *Cedrus deodara* and broad-leaved species did not show appreciable changes in height throughout the altitudinal ranges. Consequently, at the timber line no significant difference in tree height was found among the species. From these observations, reduction in tree height with the increase in elevation may be a general strategy in conifer species for surviving in stressful environment prevailing at the timberline.

As we expected, the height of all the species decreased with altitude because of greater mechanical damage or low temperature and at higher altitude trunk diameter growth is not limited by low temperature around the timberline. Takashi *et al,* 2012 suggested that tree height at the timberline is mainly affected by mechanical damage due to strong wind and snow rather than by growth limitation due to low temperature.

The results suggested that trees cannot increase their trunks height but the trunk diameter of all the species may be able to continue to grow even around the timberline. The higher biomass allocation to stem diameter may provide additional strength against strong winds. Low statured plants with lower crown area and increased diameter are considered less susceptible to snow or wind related damage. Plants with low values for height: diameter ratio (<74) are classified as stronger as and more resilient to damage than the plants with high height: diameter ratio (above 90) (Cramer, 1972). If it is true, then the present results suggest that *Abies pindrow* have greater ability to survive than other conifers confirming the high dominance of this species in these forests. High dominance of fir in upper zone of the moist temperate forest of the Himalaya differentiated it from the lower coniferous forests zones.

The causes of stunting can be discussed in terms of precipitation which appears to be lower at the summit than at the base of the mountain. Similarly the role of temperature is suggested to be the key environmental factor in determining the plant height. Many physiological aspects are influenced directly or indirectly by the temperature regime which directly affect the carbon balance of the plant. Carbon allocation rather than carbon gain is considered the critical factor that influence the carbon balance with increasing elevation. Besides the carbon gain the low temperature affects the shoot functioning such as photosynthesis, transpiration and leaf conductance and overall tree growth. Friend and Woodward's (1990) review of mountain Eco-physiology suggested that throughout the world the reduction in plant stature with altitude is an adaptation to maintain leaf temperature above air temperature. Kapos and Tanner, (1985) showed that the leaf temperature of low-stature Jamaican upper Mountain forest trees closely followed the air temperature to ensure the photosynthesis and biomass allocation.

Since the forests at upper elevation are possibly not adversely affected by poor soil conditions or nutrient limitation compared with the forests at lower altitudes it is concluded that reduction in plant stature is primarily due to low precipitation and low temperature at high altitude forests. Similar results were noted by Kronfuss and Havranek, (1999). Although, temperature difference is not great but conifers are highly sensitive to this factor suggesting adaptations to narrow ranges of environmental conditions (Brodribb *et al.* 2014). Generally, wind velocity increases with altitude (Araki, 1995; Baker and Weisberg, 1995). Strong winds in winter often cause mechanical damage of trees at high altitudes by snow abrasion due to wind-blown ice crystals; this damage causes winter desiccation (Hadley and Smith, 1983, 1986). Trunks and branches are also often broken by snow pressure (Seki *et al.* 2002). Thus, not only temperature, but also strong winds and snow are important for shift in growth pattern near the timber line. Wind also seems to have acted indirectly on trunk height. High wind speed on high altitudes during vegetative period influence air and soil temperature (cooling of air and soil) and possibly affect the activity of the apical and lateral meristems. High wind speed at the summit is considered very destructive for the forest, because trees are destroyed, crown areas reduced and emergent crowns destroyed.

We detected the trade-off among apical (vertical) growth and lateral growth (growth in diameter) along the altitudinal gradient. This trade-off is between the products of plant vegetative meristem and vascular cambium. The increasing trends in tree diameter around the timber line were not surprising but at higher altitudes the seasonal course of temperature has very strong effect on growth process of trees particularly kinetics of tree ring formation and wood production. A positive influence of early summer temperature on tree ring growth in temperate region has been reported by several workers (Briffa *et al.* 1998 a; 1998 b; Vaganov, 1996; Kirdyanov *et al.* 2003). Zimmerman and Brown, (1971) found that cambium initiation correspond the temperature of 10 days before the date of snow melt. This stage is connected with the beginning of apical development near the north timberline. Deslauriers and Morin, (2005) observed that, in *Abies* species the rate of wood production depended on minimum air temperature.

Oribe and Kubo, (1997) and Oribe *et al.* (2001, 2003) investigated that temperatures from late winter to early spring appeared to influence the physiological processes involved in the initiation of cambial activity and process of wood formation.

These factors include changes in leaf area, changes in growth energy, food manufacture and reserve material, variations in the length of growing season, variation in temperature and moisture, light, amount of seed production, release of competition (Larson, 1956). The factors cited above may be easily confused with one another and again the growth processes are very complex and cannot be attributed only one or two factors such as rainfall and temperature. Despite numerous studies, the mechanism of lateral growth in stem is still not fully explained (Chaffey, 2002).

Tree Density

In the present study, significant decline in total tree density from low to high elevations across the altitudinal strata and among sites were detected. Decline in tree density correspond well with the characteristics of most of the other timberline settings in the region where the density decreases from close canopy to open forests and even to isolated individuals marking the tree line as has been reported by previous studies (Kalakoti *et al.* 1986; Noble, 1993; Rawal and Pangtey, 1994; Dhar *et al.* 1997; Gairola *et al.* 2008). The decline in tree density might be attributed either to wind damage by uprooting or low temperature by limiting the recruitment process. This is consistent with the findings of Takahashi *et al.* (2012) who suggested that stand structure at timberline is mainly affected by mechanical damage due to strong wind and snow rather than by limitation due to low temperature alone. A negative correlation between tree density, tree height and tree crown area with altitude was found. As the seed production is proportional to tree size (Messaoud *et al.* 2007). Thereby, seed production is thought to be decreased with altitude, because of low tree density and low tree size. Therefore, regeneration and recruitment processes are greatly hampered around the timber line.

Acknowledgements

We wish to Acknowledge Mrs. Adeela Altaf, Lecturer, Department of Environmental Sciences, Bahauddin Zakariya University for their help in field work data organization and application of statistical approaches in this project. We are greatly indebted to Mr. Muhammad Tehmasip, D.F.O. Kaghan range who provided all the possible facilities in mountains forests study areas. We gratefully acknowledge the financial support of the Higher Education Commission, Pakistan, Mrs. Saima Nourin, Project Director, and all the technical staff of HEC.

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