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# Impact of climate on structure and composition of Ridge Top forests in Garhwal Himalaya

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ABSTRACT: Species association and composition on ridge top forests (RTFs) in Himalayan ranges depend on climatic factors mainly, which are not well studied. To appraise climatic response on vegetation association and composition in different RTFs along altitudinal gradients, we selected four study sites with different altitudinal ranges *viz.* (i) Hindolakhal-Narendranagar range (< 2000 m asl.), (ii) Mussoorie-Dhanolti range (1900–2900 m asl.), (iii) Chaurangikhal-Harunta range (2400–3300 m asl) and (iv) Dayara-Gidara range (2500–3750 m asl) in Garhwal Himalaya. We found that in these ranges 67 woody tree species, represented by 55 genera and 39 families were present. The most abundant families were Pinaceae and Fabaceae, represented by 6 tree species in each. Mean stand (stem) density in the forests was recorded as 597 ± 29 trees $ha^{-1}$, which ranged between 546–616 trees $ha^{-1}$ with a mean basal area of 77.25 ± 17.90 $m^2$ $ha^{-1}$ (ranging from 54.43–102.83 $m^2$ $ha^{-1}$). Cluster analysis used to show the vegetation distribution and association on the ridge top forests of various mountain ranges. Canonical Correspondence Analysis revealed that elevation and climatic factors were the dominant factors for regional differences in species composition among ridge tops.

KEY WORDS: Cluster analysis, Garhwal Himalaya, Ridge tops, Species composition, Species distribution.

## INTRODUCTION

Climate exerts a dominant control over natural distribution of the species. Climate conditions are significantly more prominent variables in the development of forest structure and vegetation associations (Behera *et al.*, 2012; Mishra *et al.*, 2013). Evidence from the fossil record (Woodward, 1988; Davis and Shaw, 2001) and form recently observed trends, proved that changing climate has a profound influence on species range expansion both upward and downward (Hughes, 2000; McCarty, 2001; Walther *et al.*, 2002). Ecological 'fingerprints' of climate change (Walther *et al.*, 2001; Permesan and Yohe, 2003) appear across a wide range of taxonomic group and geographic region (Walther *et al.*, 2002; Rosenweig *et al.*, 2007) and are being identified with increasing frequency (Walther *et al.*, 2002; Parmesan, 2006). Permesan and Yohe (2003) compiled studies on many species including alpine herbs, birds, butterflies and found an average poleward shift of 6.1 km per decade.

Plants are moved across the landscape in response to changing climate (Williams and Dumroese, 2013). Future changes in climate are projected to cause changes in vegetation distribution ranges. Several studies have attributed widespread changes in plant growth or mortality to change but these efforts were focused on general trends within a biome rather than identifying spatially coherent redistribution patterns (Pauli *et al.*, 2007; Engler *et al.*, 2009). The lack of evidence of widespread plant range shifts may reflect the limited dispersal of plant or it may simply reflect the paucity of baseline records of plant distribution (Criddle *et al.*, 2003).

The climate warming may have a number of effects on forests ecosystems including increase in plant growth rate and more biomass production, but the severity of extreme climates will cause significant negative impacts of forests (IPCC, 2007). As mountain regions cover about 24% of the total global land area (UNEP-WCMC, 2002) and there are reports on rapid climate change in mountain region during the past few decades (IPCC, 2007), understanding the changes in structural and functional attributes of forests on ridge tops across a wide range of elevation gradients will help us better predict the species migration and future productivity of the forests. Scientific forest management is decisive step towards controlling global warming and climate change, considering that forests are natural storehouse of carbon. The Himalayan forests are one of the most fascinating and characteristic entities among the forests of the world, because of their peculiar ecological feature of possessing a temperate climate within a tropical zone.

The composition and ecosystem services of Himalayan forests depend of forest structure, which is believed to be changing over time. Gottfried *et al.* (2012) reported ample evidences that ongoing climate change continuously affects the Himalayan vegetation along with its different components. Rapid geo-climatic variations at different altitudes in Himalaya generate diverse vegetation structure and high species diversity (Chawla *et al.*, 2008). Intensity of major threats to forest ecosystems and biodiversity along altitudinal

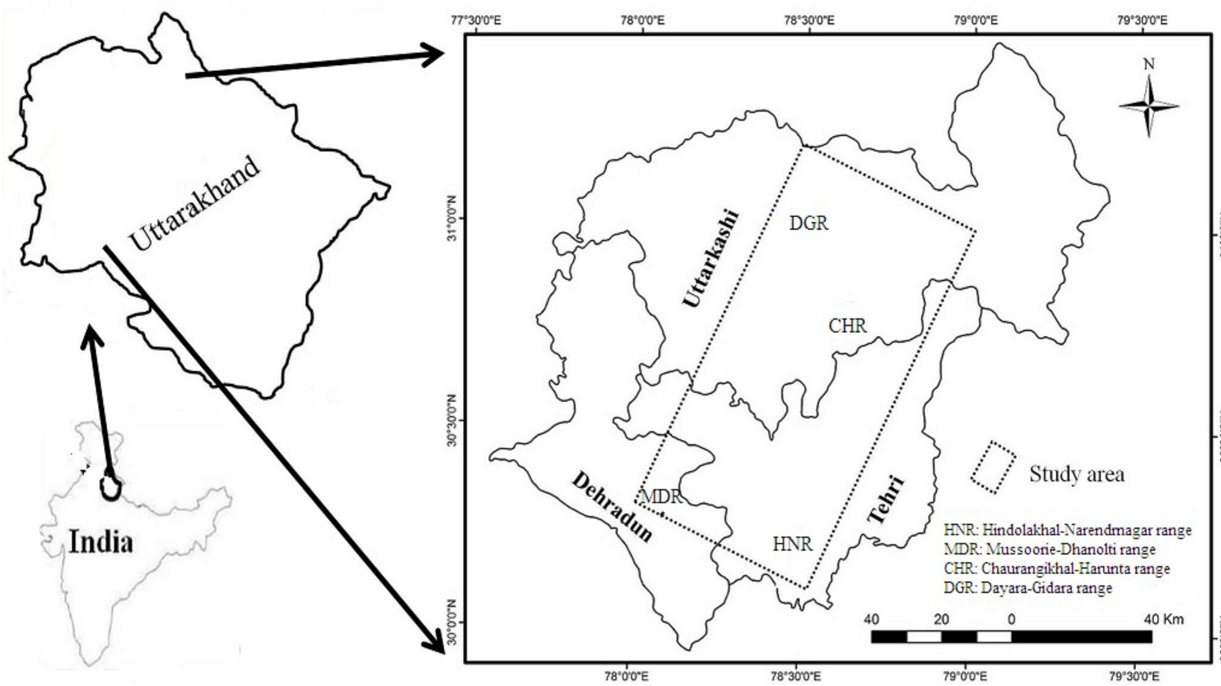


**Fig. 1.** Map representing study area.

gradient is directly measured by compositional changes in forest structure. Role of habitat loss due to fragmentation, over exploitation, invasion by alien species and global climate change is premier in disruption of community structure along the altitudinal gradient, which can be used to assess the status of forest composition and alert for future changes. Lots of work have been done on the effects of elevational gradients on forest structure and composition (Kharkwal *et al.*, 2005; Vetaas, 2006; Sharma *et al.*, 2011; Gairola *et al.*, 2012), but the studies on change in species composition on ridge tops along the altitudinal gradient in Himalaya are completely lacking.

The Himalayan ridge top ecosystems are considered to be more sensitive to global warming as they are characterized by uniform sunlight exposure and low human interferences and hence are perfect place for monitoring and comparing the effects of climate change and predicting the future changes in species composition. Furthermore, it is supposed that in the event of a rise in temperature at lower elevations the movement/migration of vegetation would be towards upper elevational ridge top. It is understandable, because the recent global warming has resulted in disturbances of ecological relationship, alteration in plant life history and general upward shift in the species distributional ranges (McKone *et al.*, 1998; Kalanderud, 2005; Jaurasinski and Kreyling, 2007; Pauli *et al.*, 2012).

In the west Himalayan region along lowest and highest elevation transects the changes in forest composition are evident, but they are required to be measured properly (Sharma *et al.*, 2014; Sharma *et al.*, 2015). Projecting future changes in species composition and distribution of vegetation on ridge tops at different altitudes is a crucial step towards planning and mitigating the impacts of climate change on biodiversity. The aim of the study is to describe and analyze the forest structure, composition and distribution pattern along elevational gradients, in order to explain the changes in forest composition and characters of forest on ridge tops in response to changing climate.

## MATERIALS AND METHODS

We selected the four Ridge Top Forests (RTFs) situated from lower to higher altitudes in Himalayan ranges *viz.*, (i) Hindolakhal-Narendrnagar range (HNR) (400–2000 m asl.), (ii) Mussoorie-Dhanolti range (MDR) (1900–2900 m asl.), (iii) Chaurangikhal-Harunta range (CHR) (2400–3300 m asl) and (iv) Dayara-Gidara range (DGR) (2500–3750 m) in Tehri and Uttarkashi district of Garhwal Himalaya (Fig. 1). The Structure and composition of the tree vegetation on RTFs were analyzed by laying out 0.1 hectare sample plots on ridge tops of the mountains from lower to higher elevations, climbing through sub-tropical, temperate to sub alpine forests. A total of 10 sample plots of 0.1 ha (one on each ridge top) were sampled in each studied range. Circumference at breast height (CBH = 1.37 m) was taken for the determination of tree basal area and calculated as $\pi r^2$ (where r is the radius). Total basal area is the sum of basal area of all species present in the forest. Basal area ($m^2$ $ha^{-1}$) was used to determine the relative dominance of a tree species. The diversity ($\bar{H}$) was determined by using Shannon index (Shannon and Weaver, 1949) as: $\bar{H} = -\Sigma(n_i/n)\log_2(n_i/n)$; where, $n_i$ was the IVI of a species and n is the sum of total IVI of all species in that site. The Simpson's concentration of dominance (Simpson, 1949) was measured as: $Cd = \Sigma P_i^2$, where, $\Sigma P_i = \Sigma(n_i/n)$, where, $n_i$ and n were same as for Shannon-Wiener diversity index. Simpson's diversity index (Simpson, 1949) was calculated as: $D=1-C_d$, where, D=Simpson's diversity and $C_d$=Simpson's concentration of dominance.

The meteorological data of year 2013-2014 for all the four different study sites were taken from the accuweather (Website: www.accuweather.com and en.climate/data/org). Monthly values of climate data were used for calculation of average annual data, which were interpreted to assess climatic impact on forest vegetation.

Climatic parameters, forest structure and composition, diversity and regeneration data were statistically analyzed. With the help of CANOCO-5 and SPSS version-16 (SPSS Inc., Chicgo, IL,USA) softwares. The results were correlated with temperature, altitude and rainfall to predict the future changes in the vegetation on ridge tops under different temperature change scenarios.

## RESULTS

### Vegetation analysis

The values of Species Richness, Stand density (SD) (stems $ha^{-1}$), Total Basal Cover (TBC) ($m^2\,ha^{-1}$), Shannon diversity index ($\bar{H}$), Simpson diversity index (C) and species similarity of different RTFs in four studied ranges are presented in Table 1. RTFs of Hindolakhal-Narendrnagar range (HNR) were dominated by *Quercus leucotrichophora, Shorea robusta* and *Anogeissus latifolia*, whereas the RTFs of Mussoorie-Dhanolti range (MDR) were dominated by *Quercus floribunda*, *Rhododendron arboreum* and *Abies pindrow*. On the other hand the RTFs of Chaurangikhal-Harunta range (CHR) were dominated by *Rhododendron arboreum, Pinus wallichiana* and *Abies pindrow* and *Cedrus deodara*, whereas RTFs of Dayara-Gidara range (DGR) were dominated by *Quercus semecarpifolia*, *Abies spectabilis* and *R. Arboreum* (Fig. 2). The stand density was highest in CHR (635 stems $ha^{-1}$), followed by MDR and DGR (538 stems $ha^{-1}$) and lowest in HNR (535 stems $ha^{-1}$). However, the TBC was highest in DGR (88.2 $m^2\,ha^{-1}$) and lowest in MDR (45.6 $m^2\,ha^{-1}$) (Table 1). A total of 67 woody tree species occurred in all

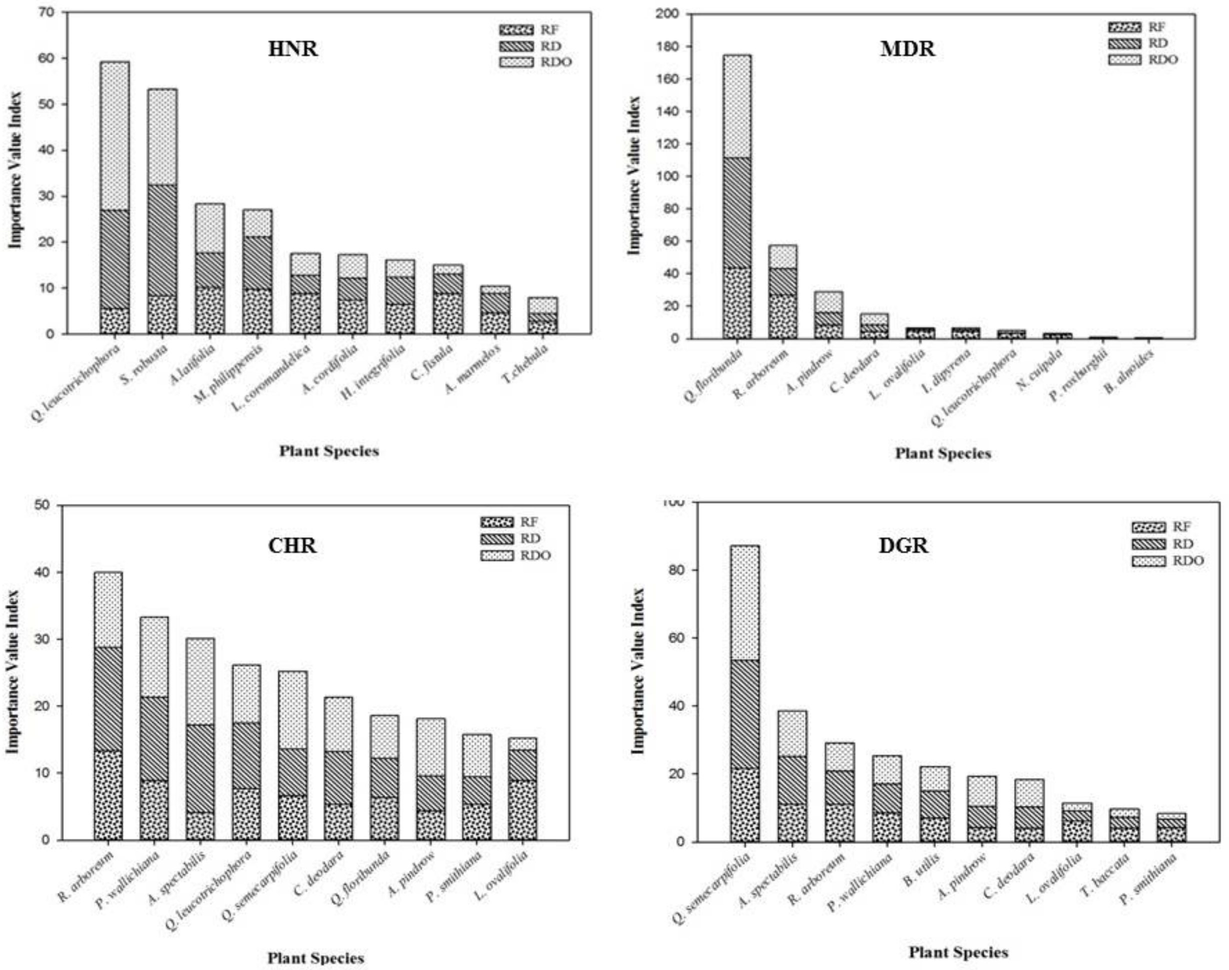


**Fig. 2.** Importance value index of dominant plant species in different study sites.

richness (33) was found in HNR and lowest (11) in MDR. The CHR forests showed the highest Shannon-Wiener diversity index (1.22), followed by HNR (1.16), DGR (1.03) and lowest in MDR (0.58). The value of concentration of dominance was highest (0.14) in DGR and lowest in HNR among all studied ranges. Vegetation similarity among four ranges were studied by Cluster analysis (Fig. 3) and HNR was observed to have highly dissimilar vegetation composition on ridge tops compared to CHR-DGR ranges which were most similar in species composition. The results of forest structure and composition of each species on RTFs of all the four ranges are given in Table 2.

**Table 1**. Structure and composition on ridge top forests in studied ranges.

| Parameters | HNR | MDR | CHR | DGR |
|---|---|---|---|---|
| Species richness | 33 | 11 | 31 | 19 |
| Genus richness | 31 | 10 | 25 | 15 |
| Families richness | 26 | 8 | 19 | 11 |
| Stem Density | 535 | 598 | 635 | 598 |
| Total basal cover | 71.9 | 45.6 | 79.9 | 88.2 |
| Simpson index | 0.01 | 0.39 | 0.08 | 0.14 |
| Shannon index | 1.16 | 0.58 | 1.22 | 1.03 |
| Similarity index | | | | |
| Hindolakhal | 1 | 0.23 | 0.28 | 0.27 |
| Mussoorie | | 1 | 0.11 | 0.12 |
| Chaurangikhal | | | 1 | 0.08 |
| Dyara-Gidara | | | | 1 |

HNR: Hindolakhal-Narendranagar range;, MDR: Mussoorie-Dhanolti range; CHR: Chaurangikhal-Harunta range and DGR: Dayara-Gidara range.

### Climate of different ranges

Climatic parameters showed wide variations among studied four ranges, represented by box plots in Fig. 4. Each box plot reflects climate variables (Temperature and Rainfall) and elevational gradients, which represents data distribution recorded every day. The line within the box marks the median of the data set; however, the top and bottom boundaries of the box indicate the 75th and 25th percentiles, respectively, while points on the bar represent the range of the data set (minimum and maximum values of variables). Altitudinal situations of studied ranges are given in Fig. 4a, which were in the order of HNR < MDR < CHR < DGR. Average monthly temperature was highest in HNR and lowest in DGR (Fig. 4b, c & d), whereas rainfall was highest in MDR and lowest in DGR (Fig. 4e).

### Climatic response on RTFs composition

Canonical Correspondence Analysis (CCA) ordination was applied for all the species (67) on the basis of their IVI values (Fig. 5). The first two CCA axes 1 and 2 accounted for 46.8% and 31.7% variation, thus covering 78.5% of total variation. Eigenvalues of the three axes is 0.28, 0.04 and 0.01. CCA results indicated that the first two axes covered most of the species distribution in ordination. Correlation between two major axes and climate data has been presented in Table 3. Axis x is highly correlated with climatic parameters.

**Table 3.** Correlation between climate factors and CCA axis scores in studied ridge top forests

| | Axis1 | Axis2 | Alt | Tmax | Tmin | Tavg | RF |
|---|---|---|---|---|---|---|---|
| Axis1 | 1 | | | | | | |
| Axis2 | .000 | 1 | | | | | |
| Alt | .985* | -.009 | 1 | | | | |
| Tmax | -.997** | -.066 | -.988* | 1 | | | |
| Tmin | -.980* | -.161 | -.984* | .992** | 1 | | |
| Tavg | -.991** | -.110 | -.988* | .998** | .997** | 1 | |
| RF | .117 | -.858 | .037 | -.041 | .083 | .014 | 1 |

*. Correlation is significant at the 0.05 level (2-tailed).
**. Correlation is significant at the 0.01 level (2-tailed).

## DISCUSSION

Results of the present study support the idea that plant species composition in Himalayan region is mainly driven by altitudinal variation in climatic factors. Various ridge tops with distinct plant communities provided an excellent base to investigate the climatic impact on plant distribution. Tree species richness was observed to be highest at HNR, followed by CHR, DGR and lowest in MDR. A monotonic decline in the number of species was observed with increasing elevation, which has often been considered as a general pattern (Brown, 1988). The MDR showed lowest species richness due to high biotic pressure prevalent in that region, whereas DGR was situated at highest elevation among the studied mountain ranges. Therefore, limitation of species on higher elevation shows the high altitude effect. Almost similar results of low species richness on higher altitudes of Garhwal Himalaya have also been reported by Rawat and Chandra (2014) and Sharma *et al.* (2014). The values of mean stand stem density and mean Total Basal Area in the studied ranges ware quite similar to the earlier reported values from Garhwal Himalaya by Pandey (2001), in which the stem density ranges from 792–1111 stems $ha^{-1}$ and TBC as 56–126 $m^2$ $ha^{-1}$. Sharma *et al.* (2011) reported almost similar tree basal area values ranging between 35.08–84.25 $m^2$ $ha^{-1}$, but high total stem density (990–1470 stems $ha^{-1}$) were recorded for moist temperate forests of Garhwal Himalaya.

According to Saxena *et al.* (1979), trees with higher girths indicate the best representation of a species in a particular environmental setup, whereas lower girths either separate the chance occurrence of the species in that area or show presence of the biotic disturbances in the past. The ridge top forests of DGR were close to climax stage, whereas the forest of MDR were young and in growing stage. Simpson dominance index has represented highest homogeneity in the forests on the ridge tops of MDR (0.39), moderate in DGR (0.14), CHR (0.08) and lowest in HNR (0.01). The dominance values were observed to be lesser than that of earlier reported ranges viz. 0.31 to 0.42 (Mishra *et al.*, 2000)

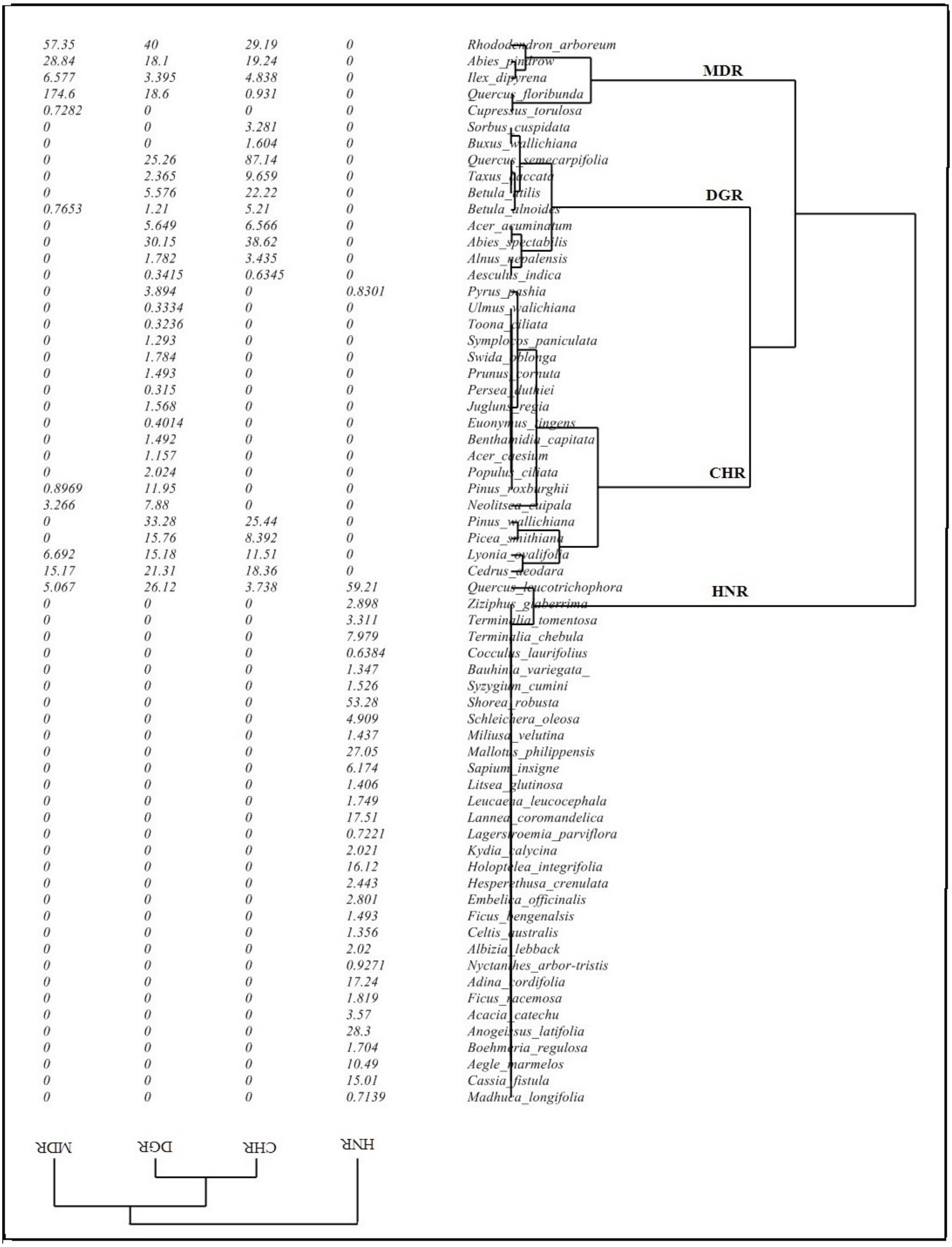


**Fig: 3.** Species composition showing species similarity with the help of Cluster analysis.

**Table 2**: Species based forest composition, biomass and carbon stocks in ridge top forests at four study ranges

| Plant species | Hindolakhal Narendranagar | | | | Mussoorie Dhanolti | | | | Chaurangi- Harunta | | | | Dyara-Gidara | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fre | Den | TBC | IVI | Fre | Den | TBC | IVI | Fre | Den | TBC | IVI | Fre | Den | TBC | IVI |
| *Abies pindrow* (D. Don) Royle | | | | | 19.44 | 45.56 | 5.77 | 28.84 | 14.17 | 33.33 | 6.79 | 18.10 | 11.67 | 37.33 | 7.66 | 19.24 |
| *Abies spectabilis* (D. Don) Spach | | | | | | | | | 13.33 | 83.33 | 10.33 | 30.15 | 30.00 | 83.67 | 11.95 | 38.62 |
| *Acacia catechu* (L. f.) Willd. | 8.93 | 4.29 | 0.17 | 3.57 | | | | | | | | | | | | |
| *Acer acuminatum* Wall. ex D. Don | | | | | | | | | 10.00 | 11.00 | 0.68 | 5.65 | 11.67 | 8.33 | 0.76 | 6.57 |
| *Acer caesium* Wall. ex Brandis | | | | | | | | | 2.50 | 1.33 | 0.14 | 1.16 | | | | |
| *Adina cordifolia* (Roxb.) Hook. f. ex Brandis | 28.57 | 25.00 | 1.89 | 17.24 | | | | | | | | | | | | |
| *Aegle marmelos* (L.) Correa | 17.86 | 22.86 | 0.58 | 10.49 | | | | | | | | | | | | |
| *Aesculus indica* (Wall. ex Cambess.) Hook. | | | | | | | | | 0.83 | 0.33 | 0.03 | 0.34 | 0.83 | 1.00 | 0.14 | 0.63 |
| *Albizia lebbeck* (L.) Benth. | 5.36 | 2.14 | 0.08 | 2.02 | | | | | | | | | | | | |
| *Alnus nepalensis* D. Don | | | | | | | | | 2.50 | 2.67 | 0.47 | 1.78 | 4.17 | 4.33 | 1.03 | 3.44 |
| *Anogeissus latifolia* (Roxb. ex DC.) Wall. ex Guill. & Perr. | 39.29 | 40.00 | 3.90 | 28.30 | | | | | | | | | | | | |
| Bauhinia variegata Linn. | 3.57 | 1.43 | 0.06 | 1.35 | | | | | | | | | | | | |
| *Benthamidia capitata* (Wall.) H. Hara | | | | | | | | | 2.50 | 3.33 | 0.16 | 1.49 | | | | |
| *Betula alnoides* Buch.-Ham. ex D. Don | | | | | 1.39 | 0.56 | 0.03 | 0.77 | 2.50 | 2.00 | 0.10 | 1.21 | 6.67 | 9.33 | 1.05 | 5.21 |
| *Betula utilis* D. Don | | | | | | | | | 9.17 | 8.67 | 1.12 | 5.58 | 19.17 | 47.00 | 6.42 | 22.22 |
| *Boehmeria rugulosa* Wedd. | 3.57 | 1.43 | 0.00 | 1.70 | | | | | | | | | | | | |
| *Buxus wallichiana* Baill. | | | | | | | | | | | | | 3.33 | 1.67 | 0.08 | 1.60 |
| *Cassia fistula* L. | 33.93 | 22.86 | 0.71 | 15.01 | | | | | | | | | | | | |
| *Cedrus deodara* (Roxb. ex D. Don) G. Don | | | | | 9.72 | 24.44 | 3.10 | 15.17 | 17.50 | 50.00 | 6.44 | 21.31 | 10.83 | 37.00 | 7.21 | 18.36 |
| *Celtis australis* L. | 1.79 | 1.43 | 0.23 | 1.36 | | | | | | | | | | | | |
| *Cocculus laurifolius* DC. | 1.79 | 0.71 | 0.02 | 0.64 | | | | | | | | | | | | |
| *Cornus oblonga* Wall. | | | | | | | | | 4.17 | 2.33 | 0.11 | 1.78 | | | | |
| *Cupressus torulosa* D. Don | | | | | 1.39 | 0.56 | 0.01 | 0.73 | | | | | | | | |
| Euonymus tingens Wallich in Roxburgh | | | | | | | | | 0.83 | 0.33 | 0.07 | 0.40 | | | | |
| *Falconeria insignis* Royle | 14.29 | 8.57 | 0.32 | 6.17 | | | | | | | | | | | | |
| *Ficus benghalensis* L. | 1.79 | 0.71 | 0.33 | 1.49 | | | | | | | | | | | | |
| *Ficus racemosa* L. | 3.57 | 2.14 | 0.18 | 1.82 | | | | | | | | | | | | |
| *Hesperethusa crenulata* (Roxb.) M. Roem. | 5.36 | 2.86 | 0.19 | 2.44 | | | | | | | | | | | | |
| *Holoptelea integrifolia* (Roxb.) Planch. | 25.00 | 31.43 | 1.38 | 16.12 | | | | | | | | | | | | |
| *Ilex dipyrena* Wall. | | | | | 9.72 | 7.22 | 0.49 | 6.58 | 7.50 | 4.67 | 0.29 | 3.40 | 9.17 | 6.33 | 0.35 | 4.84 |
| *Juglans regia* L. | | | | | | | | | 1.67 | 0.67 | 0.76 | 1.57 | | | | |
| *Kydia calycina* Roxb. | 3.57 | 2.14 | 0.03 | 1.41 | | | | | | | | | | | | |
| *Lagerstroemia parviflora Roxb.* | 1.79 | 0.71 | 0.05 | 0.72 | | | | | | | | | | | | |
| *Lannea coromandelica* (Houtt.) Merr. | 33.93 | 21.43 | 1.73 | 17.51 | | | | | | | | | | | | |
| *Leucaena leucocephala* (Lam.) de Wit | 1.79 | 3.57 | 0.23 | 1.75 | | | | | | | | | | | | |
| *Lindera pulcherrima* (Nees) Benth. ex Hook. f. | 3.57 | 1.43 | 0.30 | 2.02 | | | | | | | | | | | | |
| *Lyonia ovalifolia* (Wall.) Drude | | | | | 11.11 | 6.67 | 0.31 | 6.69 | 29.17 | 28.67 | 1.37 | 15.18 | 16.67 | 18.33 | 2.02 | 11.51 |
| *Madhuca longifolia* (L.) J. F. Macbr. | 1.79 | 0.71 | 0.04 | 0.71 | | | | | | | | | | | | |
| *Mallotus philippensis* (Lam.) Mull. Arg. | 37.50 | 60.71 | 2.19 | 27.05 | | | | | | | | | | | | |
| *Miliusa tomentosa* (Roxb.) J. Sinclair | 3.57 | 2.14 | 0.04 | 1.44 | | | | | | | | | | | | |
| *Neolitsea cuipala* (Buch.-Ham. ex D. Don) Kosterm. | | | | | 5.56 | 3.89 | 0.07 | 3.27 | 10.83 | 20.33 | 1.08 | 7.88 | | | | |
| *Nyctanthes arbor-tristis* L. | 1.79 | 1.43 | 0.07 | 0.93 | | | | | | | | | | | | |
| Persea duthiei (King ex Hook. f.) | | | | | | | | | 0.83 | 0.33 | 0.01 | 0.31 | | | | |
| *Phyllanthus emblica* L. | 7.14 | 2.86 | 0.15 | 2.80 | | | | | | | | | | | | |
| *Picea smithiana* (Wall.) Boiss. | | | | | | | | | 17.50 | 26.00 | 5.03 | 15.76 | 11.67 | 14.67 | 1.44 | 8.39 |
| *Pinus roxburghii* Sarg. | | | | | 1.39 | 1.11 | 0.04 | 0.90 | 13.33 | 19.00 | 3.89 | 11.95 | | | | |
| *Pinus wallichiana* A. B. Jacks. | | | | | | | | | 29.17 | 78.67 | 9.54 | 33.28 | 23.33 | 50.67 | 7.36 | 25.44 |
| *Populus ciliata* Wall. ex Royle | | | | | | | | | 4.17 | 2.00 | 0.34 | 2.02 | | | | |
| *Prunus cornuta* (Wall. ex Royle) Steud. | | | | | | | | | 2.50 | 2.33 | 0.29 | 1.49 | | | | |
| *Pyrus pashia* Buch.-Ham. ex D. Don | 1.79 | 1.43 | 0.04 | 0.83 | | | | | 8.33 | 7.00 | 0.19 | 3.89 | | | | |
| *Quercus floribunda* Lindl. ex A. Camus | | | | | 98.61 | 407.22 | 28.75 | 174.64 | 20.83 | 37.00 | 5.09 | 18.60 | 1.67 | 1.33 | 0.08 | 0.93 |
| *Quercus leucotrichophora* A. Camus | 21.43 | 114.29 | 11.84 | 59.21 | 6.94 | 3.89 | 0.62 | 5.07 | 25.00 | 62.33 | 6.90 | 26.12 | 5.00 | 4.67 | 0.98 | 3.74 |
| *Quercus semecarpifolia* Sm. | | | | | | | | | 21.67 | 44.33 | 9.29 | 25.26 | 58.33 | 190.33 | 29.78 | 87.14 |
| *Rhododendron arboreum* Sm. | | | | | 61.11 | 97.22 | 6.44 | 57.35 | 43.33 | 98.33 | 8.95 | 40.00 | 30.00 | 58.33 | 7.37 | 29.19 |
| *Schleichera oleosa* (Lour.) Oken | 10.71 | 7.14 | 0.29 | 4.91 | | | | | | | | | | | | |
| *Shorea robusta* C. F. Gaertn. | 32.14 | 129.29 | 7.62 | 53.28 | | | | | | | | | | | | |
| *Sorbus cuspidata* Hedl. | | | | | | | | | | | | | 5.83 | 4.00 | 0.40 | 3.28 |
| *Symplocos paniculata* Miq. | | | | | | | | | 3.33 | 1.33 | 0.05 | 1.29 | | | | |
| *Syzygium cumini* (L.) Skeels | 3.57 | 1.43 | 0.12 | 1.53 | | | | | | | | | | | | |
| *Taxus wallichiana* Zucc. | | | | | | | | | 5.00 | 2.67 | 0.33 | 2.37 | 10.83 | 19.33 | 2.14 | 9.66 |
| *Terminalia chebula* Retz. | 10.71 | 9.29 | 1.27 | 7.98 | | | | | | | | | | | | |
| *Terminalia elliptica* Willd. | 7.14 | 3.57 | 0.29 | 3.31 | | | | | | | | | | | | |
| *Toona ciliata* M. Roem. | | | | | | | | | 0.83 | 0.33 | 0.01 | 0.32 | | | | |
| *Ulmus wallichiana* Planch. | | | | | | | | | 0.83 | 0.33 | 0.02 | 0.33 | | | | |
| *Ziziphus xylopyrus* (Retz.) Willd. | 7.14 | 3.57 | 0.14 | 2.90 | | | | | | | | | | | | |
| **Grand total** | 385.71 | 535.00 | 8.47 | 300.00 | 226.39 | 598.33 | 8.90 | 300.00 | 325.83 | 635.00 | 79.86 | 300.00 | 270.83 | 597.67 | 88.22 | 300.00 |

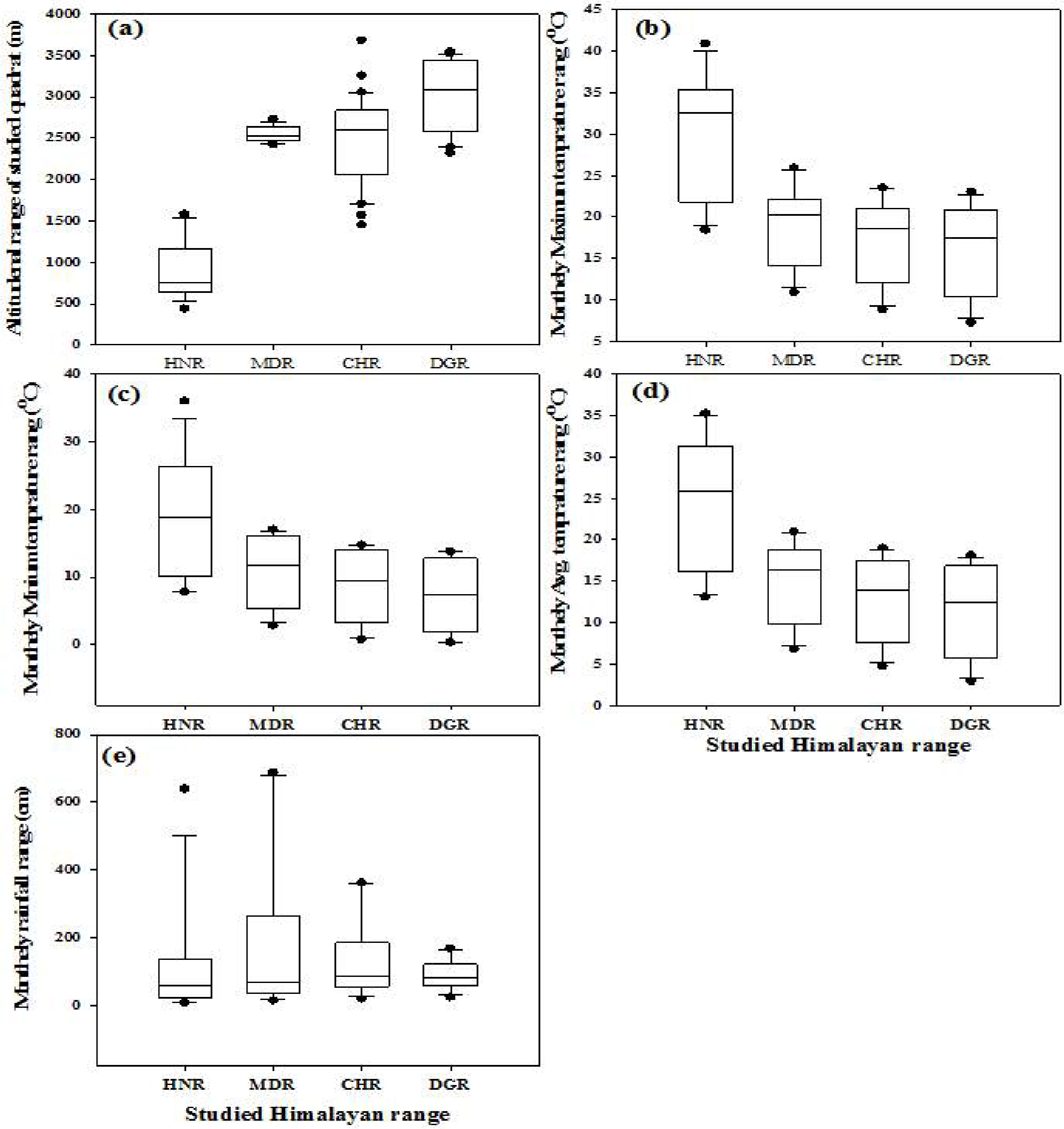


**Fig. 4.** Altitudnal and climate variations in different studied sites.

and 0.11 to 0.93 (Tiwari and Singh, 1985), for the forest of Uttarakhand Himalaya. Along the altitude, the geographic and climatic conditions change sharply (Kharkwal *et al.*, 2005), therefore, the Jaccard similarity index value for vegetation association was higher in CHR and HNR ranges and lower in MDR and DGR ranges. Champion and Seth (1968) categorize *S. robusta, A. latifolia* and *P. roxburghii* as the early successional species and *C. deodara* and *Q. semecarpifolia* as climatic climax forming species. Therefore, the forests in HNR and MDR ranges were young and in successional stage whereas in CHR and DGR ranges the forests were in climax stage (dominated by *C. deodara* and *Q. semecarpifolia*). The Cluster analysis results demonstrated that the forest composition and vegetation structure whereas, CCA results revealed the impact of climate factors on the vegetation of the studied ranges. The Cluster analysis has shown that the vegetation of CHR and DGR were similar in species composition, compared to other ridge tops, however, the HNR forests were having highly dissimilar composition than other ridge tops because they were close to habitation zone. CCA study visibly displayed temperature was the main factor to

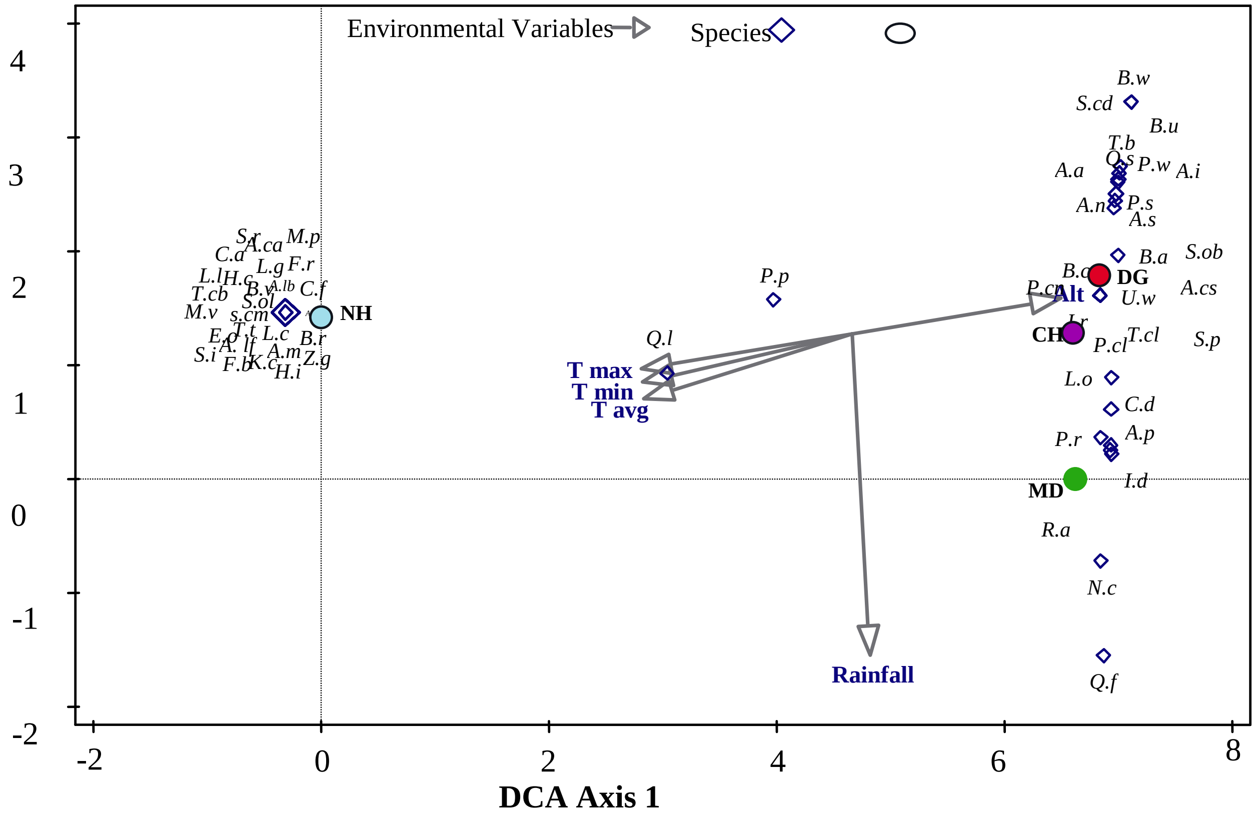


**Fig. 5.** Response of climatic and altitudinal impacts on forest composition.

differentiate HNR vegetation to other three ranges. Vegetation structure of MDR was majorly governed by rainfall, which played a key role for differentiate the vegetation of this range to others. The results of correlation study revealed that in topographic factors, altitude was significantly, negatively correlated with atmospheric temperatures and there was no significant difference between altitude and rainfall. Composition of I$^{st}$ axis plant species were significantly, positively correlated with altitude and significantly, negatively correlated with atmospheric temperature.

The *C. deodara* , *R. arboretum, L. ovalifolia, Q. semecarpifolia, Q. leucotrichophor*, *P. wallichiana* , *P. smithiana*, *P. roxburghii* etc. were the dominant, widely distributed and well adapted species on various altitudes, which helped them to flourish throughout the study area. The study has also revealed that the forest structure of HNR was regulated by temperature and rain fall, whereas the forests on ridge tops of DGR and CHR were regulated by altitudinal variation only. Thus, it is concluded that the species association and composition on RTFs in Himalayan ranges depend on climatic factors. Quantification of the current forest composition on the ridge tops is crucial in order to assess the role of climate change on future species coexistence and species shift in Himalayan ranges. Along the climatic variation, lower elevational ridge tops had comparatively high species richness than higher elevational ridge tops, which show the climatic adaptation of plant species.

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