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Altitudinal variation in plant community, population structure and carbon stock of *Quercus semecarpifolia* Sm. forest in Kumaun Himalaya

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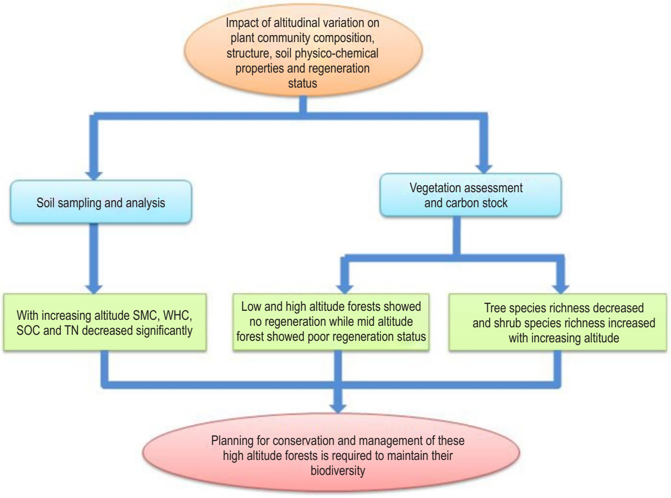
Abstract

Aim: To study the impact of altitudinal variation on plant community composition, structure, dispersion and regeneration status of *Quercus semecarpifolia* forest in Kumaun Himalaya.

Methodology: Along the altitudinal gradient, the forest stands between 2400 and 2610 m asl were selected at low, mid and high altitude. The phyto-sociological analysis was carried by laying ten quadrats of 10m × 10m at each site. Soil samples were collected with the help of soil corer from two depths. Various ecological indices and population structure were investigated for each forest stand and regeneration status of forest was predicted by the population size of seedlings, saplings and trees. Tree biomass was estimated using allomatric equations and carbon stock was determined by multiplying biomass of species to factor 0.475.

Results: With increasing altitude the number of tree species decreased and the shrub species richness increased, while herb species showed a unimodel pattern. *Q. semecarpifolia* was the dominant tree species at all the three sites with the IVI values of 220.14, 255.22 and 286.23 at LA, MA and HA, respectively. A complete absence of *Q. semecarpifolia* seedlings indicated no regeneration in low and high altitude stands while low proportion of seedlings in mid altitude forest stand indicated poor regeneration. Soil was acidic (pH 5.66-5.86), with higher silt content and showed decreasing pattern in physico-chemical properties with increasing altitude. The biomass of tree layer ranged from 871.49 to 1050.17 t ha^{-1}. The tree layer carbon stock was maximum in high altitude forest (498.84 t ha^{-1}) which was largely contributed by bole, stump roots and branches.

Interpretation: Variation in species richness, distribution pattern and regeneration potential is related to site characteristics governed by altitude and require various efforts to conserve and protect these forests to check ecosystem imbalance.



Key words: Carbon stock, Plant diversity, *Quercus semecarpifolia*, Regeneration

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Introduction

Together as an ecosystem, forests provide the exact balance life needs to thrive. Diversification of trees is essential for total forest diversity (Huang *et al.,* 2003) as trees furnish resources and habitats for nearly all other species. In a plant community, the prerequisite condition to study the overall basic structure and function of any forest ecosystem is to have knowledge about its floristic composition (Singh and Singh, 1992). The processes that can both increase or erode diversity of forest ecosystem are influenced by many types of environmental changes (Bargali *et al.,* 2018). Kharkwal *et al.* (2005) have pointed out that altitude and climatic variables like temperature and rainfall are the determinants of species composition and diversity in a forest ecosystem. Altitude itself represents a complex combination of related climatic variables closely correlated with numerous other environmental properties, *i.e.,* soil texture, nutrients, substrate stability etc. Within one altitude the cofactors like topography, aspect, inclination of slope and soil type further effect the forest composition (Manral *et al.,* 2020).

Oak has been a sign of persistent, strength and endurance throughout the history (Zobel *et al.,* 1995) having higher ecological and practical value as they are the source of fodder and fire wood in the Himalayan region (Bargali *et al.,* 2014, 2015). But the regeneration potential of oak is poor in Himalayan region (Bargali and Bargali, 1999; Karki *et al.,* 2017) and even in North America (Lorimer *et al.,* 1994) and Europe (Andersson, 1991). In the Central Himalayan forests, *Quercus semecarpifolia* Sm. (Brown/Kharsu oak) is a species which forms climax vegetation between 2200-2600 m elevation and exists as a dominant specie that plays an important role in water and soil conservation (Singh and Singh, 1992; Bargali *et al.,* 2014, 2015). Being a dominant species this Brown Oak forms unadulterated forest strands and climax community for most parts on the southern aspect (Negi and Naithani, 1995) and provides food for a huge range of fauna, closed canopy for sciophytes, stems, branches and bough for vascular and non-vascular epiphytes, and litter to maintain soil fertility (Shreshtha, 2003). Studies indicate that Brown Oak gives rise to a good seed crop at 2-3 year interlude even so this important Himalayan Oak is lacking to regenerate (Troup, 1921). In the Himalayan region of India and Nepal, *Q. semecarpifolia* forests are diminishing and degrading because of over-utilization and very steady growth rate (Singh and Singh, 1992; Bargali *et al.,* 2014). Natural regeneration of this Brown Oak is very poor and unexpectedly it is failing to grow even beneath its own canopy (Shreshtha, 2003).

Unprecedented changes are happening in plant community structure and regeneration patterns in the Himalayan region forests due to climatic changes and various human activities such as lopping, fragmentation of forests for agricultural land and cutting of trees for fuel, fodder and grazing (Bargali *et al.,* 1987; Gosain *et al.,* 2015; Bargali *et al.,* 2015; Karki *et al.,* 2017; Manral *et al.,* 2020). From the population structure, the regeneration behaviour of tree species in any forest can be determined and for successful regeneration there must be the presence of abundant number of seedlings, saplings and young trees (Saxena and Singh, 1984). Altitudinal gradients provide natural climatic variation in which key environmental factors and soil physico-chemical properties change considerably within a confined area that affect plant growth, development and influence the community structure, function and regeneration (Read *et al.,* 2014; Baumler, 2015; Bargali *et al.,* 2018).

This study was conducted in a natural *Q. semecarpifolia* forest of Kumaun Himalaya. In the Himalayan belt, soil as well as vegetation change within a short distance (Baumler, 2015) may affect the structure and functioning of the *Q. semecarpifolia* forest. In view of the above, this study was carried out to analyze the altitudinal variation in plant community structure and the impact of altitude on regeneration pattern, biomass and carbon stock for conservation and sustainable utilization of forest resources in temperate region of Kumaun Himalaya.

Materials and Methods

Study site: The study was conducted in Cheena peak Kharsu oak (*Q. semecarpifolia*) temperate forest (29˚24’19.02”N to 29˚24’29.12” N latitude and 79˚26’00.75”E to 79˚26’11.81”E longitudes) in district Nainital of Kumaun Himalaya situated 5 km away from Nainital town (Fig. 1). The sites were selected between 2400-2610 m asl at South-East aspect and divided on the basis of elevation into Low altitude (LA : 2400-2460 m), Mid altitude (MA : 2460-2530 m) and High altitude (HA : 2530-2610 m). Climate of study site is temperate monsoon type having three main seasons, winter (November to February), summer (April to mid June) and rainy (mid June to September). The mean minimum temperature ranged from 5˚C to 21˚C and the mean maximum temperature varied from 17˚C to 28˚C, while the normal annual rainfall averaged 130.92 mm and the mean monthly rainfall ranged between 3.7 and 451.38 mm (Fig. 2).

Sampling design: The patterns of forest structure were assessed along the elevation gradient in the selected three altitudinal ranges. The size of the quadrats for sampling tree, shrub, and herb species were determined by the species-area-curve method (Muller-Dombois and Ellenberg, 1974). Following a stratified random sampling approach, at each site, 0.1 ha permanent plot were established. Ten quadrats of 10m × 10m size for the tree, sapling and seedling layer; twenty quadrats of 5m × 5m size for shrubs and thirty quadrats of 1m × 1m size for herbs were randomly laid out at each site. The individuals >30cm cbh were categorized as trees, and 10–30 cm cbh as saplings and <10 cm as seedlings (Pande *et al.,* 2014). Circumference at breast height (cbh, *i.e.,* 1.37 m above the ground) was measured for each individual tree and sapling, while harvest method was used for counting and identifying the herb layer.

The plants were identified with the help of herbarium available in the Department of Botany, Kumaun University, Nainital. Basal area, density, and importance value index (IVI)

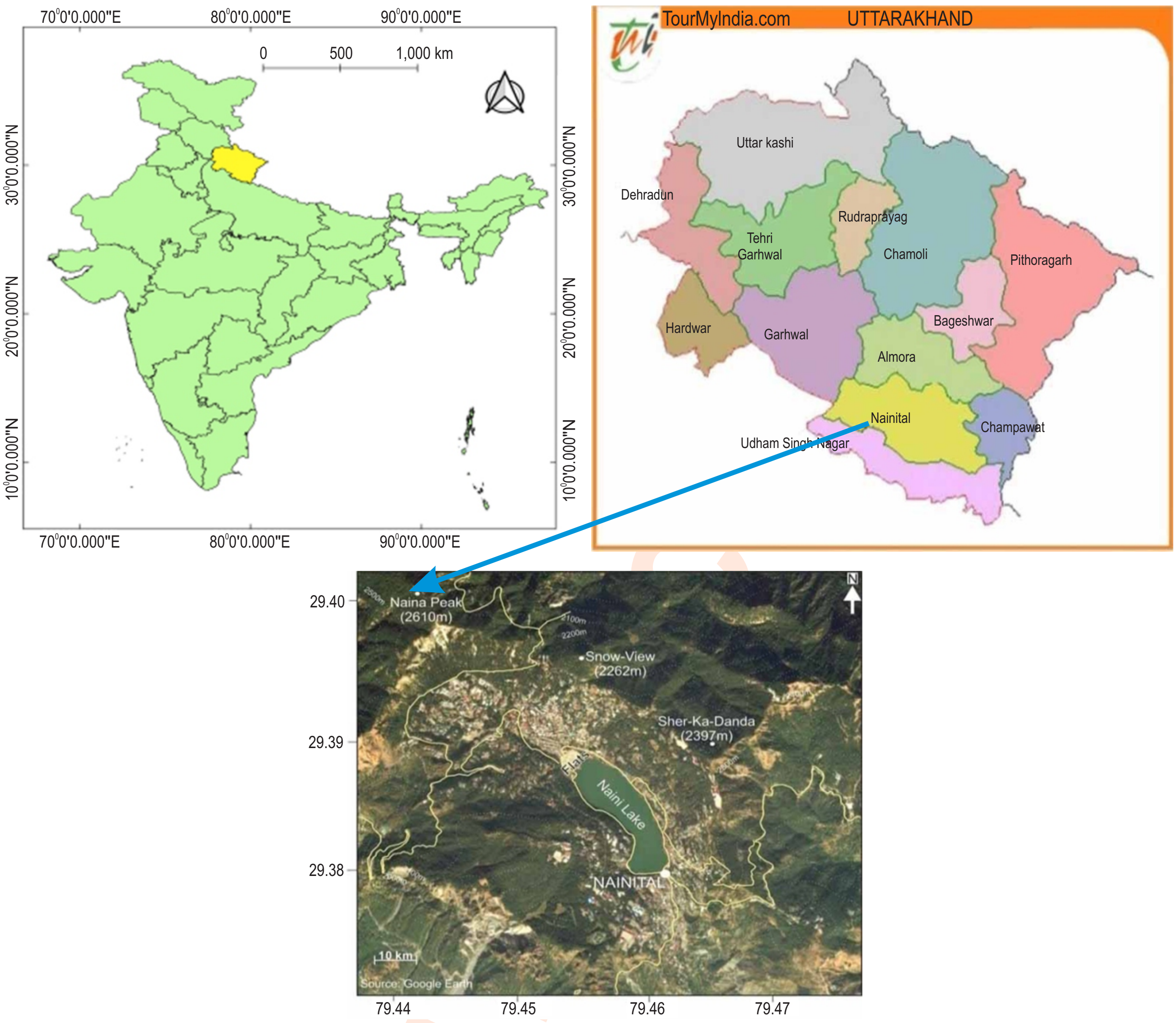

Fig. 1: Location map of study area

were calculated according to the formulae of Cottam and Curtis (1956). For shrubs and herbs, Provenance value (PV= RF+RD) was calculated by summing up the values of relative frequency and relative density. Diversity of the species was calculated using Shannon-Weiner Index (Shannon and Weaver, 1949): $H' = -Pi \log_2 Pi$

Where, Pi is the proportion of total stand basal area represented by the i^{st} species.

The working formula given by Smith (1999) was used here as: $H' = 3.322 [Ni/N \log_{10} Ni/N)]$

Concentration of dominance was calculated by Simpson's index (Simpson, 1949): $Cd = (Ni/N)^2$

Where, Ni is the total number of individuals of a species and N is the total number of individuals of all species. Species richness was simply indicated by the total number of species in a given forest site or the number of species per unit area (Whittaker, 1965). Equitability or Evenness (E) was calculated by the formula (Pielou, 1996): $e = H'/\ln S$

Where, H' is the Shannon index and S is the number of species.

Using species richness values in different sites, index of similarity between pairs of stands was calculated (Mueller and

Ellenberg, 1974): Index of similarity (IS) = IS=2C×100/ (A+B)

Where, A is the number of species at site A, B is the number of species at site B and C is the common species at both the sites. The regeneration status of tree species was determined based on the population size of seedlings, saplings, and adults (Shankar, 2001). Biomass was estimated by the allometric equation for each tree component following Rawat and Singh (1988) and Adhikari *et al*. (1995) as: ln y = a+b ln x

Where, a = y-intercept, b = slope or regression coefficient and x = CBH (cm) and y = weight of components of tree (kg tree^{-1}). Carbon stock was determined using the biomass value of species multiplied by factor (C = Biomass × 0.475) as given by Magnussen and Reed (2004).

Soil samples were collected at random points in replicates of three within each selected site from two depths (0-15 cm and 15-30 cm) with the help of a soil corer. Soil texture was determined hydrometrically using sieves of different pore size. Gravimetrical method was used to determine the soil moisture content (SMC) and bulk density (bD) was calculated as the proportion of oven dried soil and corer volume and porosity was calculated following Kumar and Ram (2005). Water holding capacity (WHC) was determined following Piper (1950) and soil pH was measured using a pH meter. Soil organic carbon (SOC) was analysed by Walkley and Black (1934) method, total nitrogen (TN) was estimated using Kjeldahl digestion and distillation unit.

Data analysis: The collected data replicates were analyzed using SPSS Version 16. ANOVA (Analysis of Variance) and Pearson's correlation were carried out to determine the statistical significance using SPSS version 16. The paired t-test was used to estimate the significant differences between soil depths (0-15cm and 15-30cm). Principal Component Analysis (PCA) was conducted to explain the variance of analyzed vegetation and soil attributes using PAST software package.

Results and Discussion

Floristic composition: A total of 31 species (7 trees, 4 shrubs and 20 herbs) of 29 genera and 22 families were recorded at all the three study sites. Among 31 species, 17 species (4 trees, 4 shrubs and 9 herbs) were recorded as monotypic as they were represented by a single specie. The contribution of tree, shrub and herb species to total species richness was 22.58%, 12.90% and 64.51%, respectively. In low altitude, 27 species (trees, shrubs and herbs) of 25 genera and 20 families were recorded. In mid altitude, 20 species (trees, shrubs and herbs) of 20 genera and 11 families were recorded whereas in high altitude, 25 species (trees, shrubs and herbs) of 25 genera and 20 families were recorded. *Q. semecarpifolia* was dominant tree species at all the three altitudes, while the composition and co-dominant species varied from LA to HA (Table 1). In the shrub layer, only 4 species were reported of which *Berberis chitria* was dominant at MA and HA with PV value 89.36 and 63.64, respectively, while *Rosa macrophylla* (PV= 72.82) was dominant at LA (Table 2).

In herbaceous layer, 20 species were recorded, of which 12 species were present in all the three sites. *Apluda mutica* with PV values as 83.79 and 42.81 was dominant at LA and MA, respectively, while *Vallisneria wallichiana* (PV= 40.79) was dominant at HA. Among the tree species, the maximum density was reported for *Q. semecarpifolia* (980 individual ha^{-1}) at HA, while the minimum density (20 individuals ha^{-1}) was reported for *Q. lanuginosa* and *Rhododendron arboreum* at LA and MA, respectively. Tree density and total basal area (TBA) increased with increasing altitude (Table 3). Density showed significant positive correlation with TBA, H' and Cd (Table 4). The total density value of trees (850- 1000 individuals ha^{-1}) falls within the

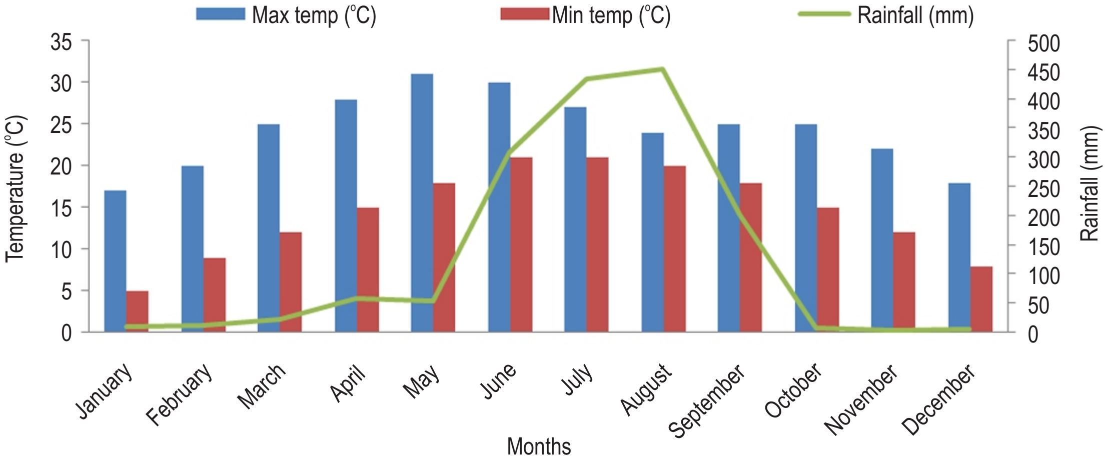

Fig. 2: Meteorological data of studied site, Year- 2017-18 (Source https://www.weather.ind.com)

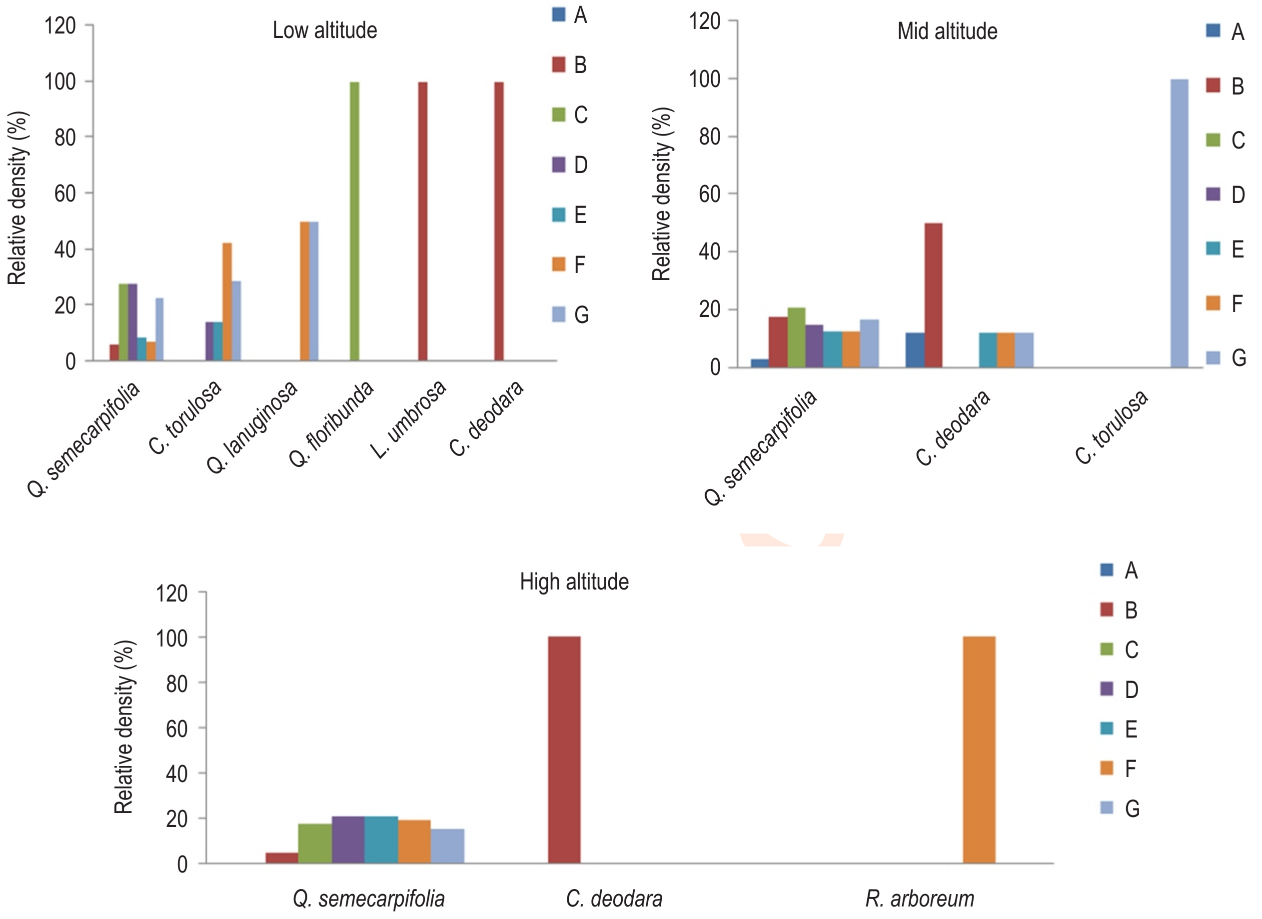

Fig. 3: Regeneration patterns of tree species in different sites. A = seedlings, B = saplings. C= 30.1-60cm, D= 60.1-90cm, E= 90.1-120cm, F= 120.1-150cm and G = > 150cm CBH.

range (270 to 1670 individuals ha^{-1}) reported for temperate forest by Ghildiyal *et al.* (1998) and Ram *et al.* (2004).

TBA of trees ranged between 76.55 m^2 ha^{-1} and 90.03 m^2 ha^{-1} which was higher than the values reported by Tripathi *et al.* (1991), Bargali *et al.* (2011). Sharma *et al.* (2014) also reported similar TBA (89.7 m^2 ha^{-1}) for high mountain *Q. semecarpifolia* forest in Garhwal Himalaya. The sapling density (60 to 220 individuals ha^{-1}) was lower than the values reported by Zobel *et al.* (1995) for the *Q. leucotrichophora* and *Pinus roxburghii* forests around Nainital. The seedlings were present only at mid altitude which was much lower than the values reported by Joshi and Tewari, (2011). According to Tripathi *et al.* (1991), high mountains have a particular climatic setup which supports high TBA values to flourish plant species and lower TBA at lower elevations may be the reason of biotic interference and disturbance in past years (Saxena and Singh, 1984). The total density of shrubs ranged between 1040 individuals ha^{-1} at low altitude and 1460 individuals ha^{-1} at high altitude. The total herb density ranged between 75.04 herbs m^{-2} at HA and 158.85 herbs m^{-2} at low altitude.

Population structure and regeneration status of tree species: The overall absence of seedlings at LA and HA indicated no regeneration in LA and HA, except for fair regeneration status at MA (Fig. 3). *Q. semecarpifolia* was represented by all size classes, except seedlings indicating that this species reproduced well at first but at present its regeneration has stopped in LA. At MA, a lower proportion of its seedlings as compared to saplings and trees indicated that this species once gave rise to profuse population with better transformation rate but at present the seedlings are not coming up regularly. The species might have produced seeds in the past but environment conditions could not support their proper establishment (Baboo *et al.,* 2017). At HA, *Q. semecarpifolia* seedlings were absent and were represented only by intermediate size classes. The failure of brown oak to regenerate in Central Himalayas is the case of environmental semi surprise (Singh *et al.,* 1997). It seems that in the current chronic form of disturbance in LA and HA, gaps formed are too small to enable this species to establish seedlings and in large gaps, grazing/browsing does not allow the regeneration of this species. Knight (1975) referred the species showing such

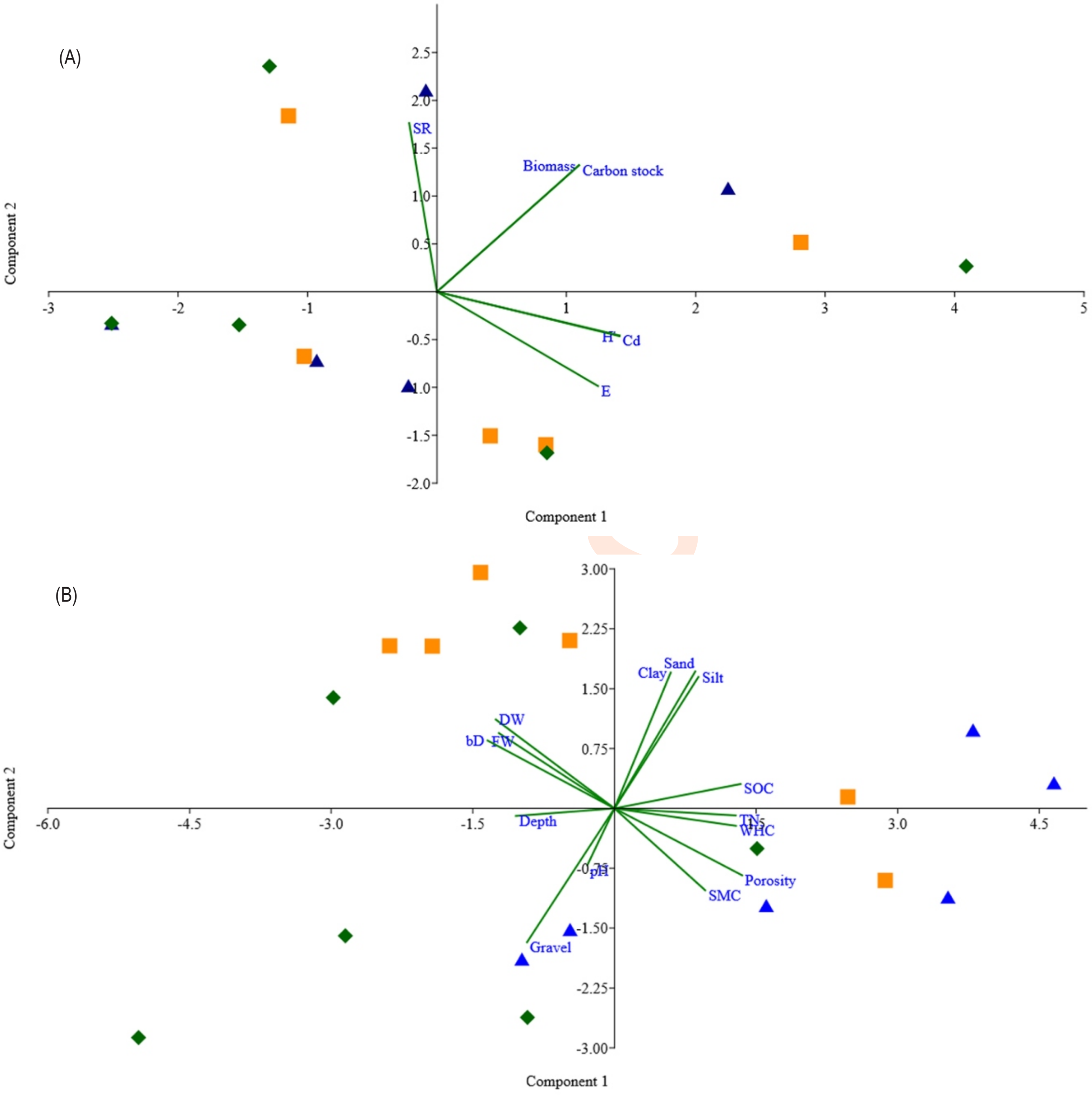

Fig. 4: Principal component analysis correlation (% variance) diagram based on vegetation and soil physico-chemical characteristics in *Quercus semecarpifolia* forest (LA= blue triangle shape; MA= orange square shape; HA= green diamod shape). (A) Vegetation attributes (where H': diversity index; Cd: dominance index; E: evenness index); (B) Soil physico-chemical attributes (where SMC: Soil moisture content, FW: Fresh weight, DW: Dry weight, WHC: Water holding capacity, SOC: Soil organic carbon, TN: Total Nitrogen).

population as infrequent reproducer. At LA, *Q. floribunda, L. umbrosa* and *C. deodara* were represented by only one size class which indicates that these species were vagrant and may accidentally present there (Van Steenis, 1958), while at MA, *C. deodara* individuals were present in lower and higher size classes and absent in intermediate classes. In HA, *C. deodara* was represented as saplings only indicating that this species is recent invader and may become canopy/sub canopy species later on. *C. torulosa* was represented by only higher size classes at LA, which indicated that there were not enough seedlings and saplings to replace trees whereas it was represented by only one large size class at MA, and thus was

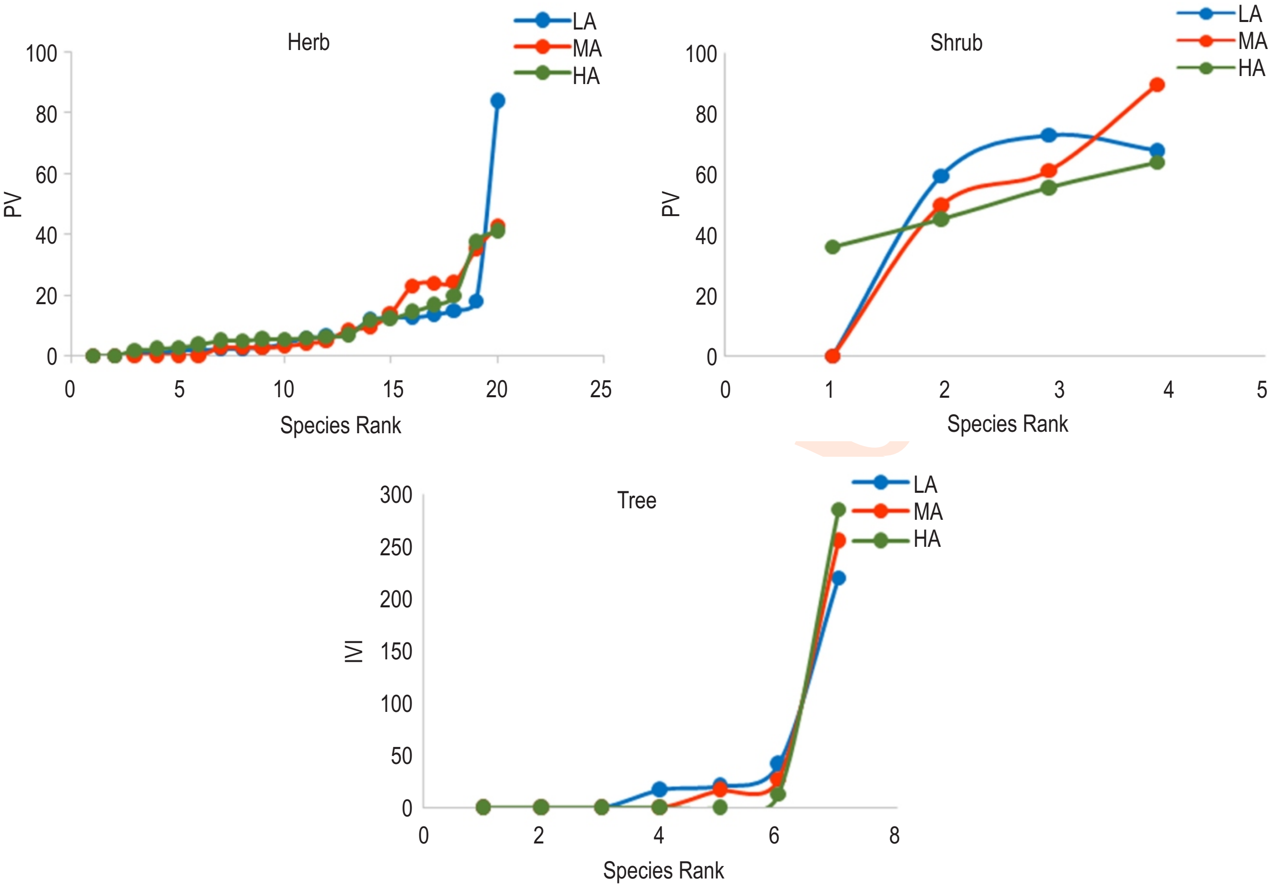

Fig. 5: Dominance diversity curve of study area.

either nomad or relict. *R. arboreum* was represented by only one large size class at HA, which indicates that this species was accidentally present in the study site (Fig. 3).

The inadequate regeneration may be due to climate change, human impact, chronic disturbance, frequent forest fire, soil erosion, uncontrolled lopping, low viability of seeds, cutting and shedding of plants for fuel and fodder, grazing and acorn predation by animals and birds (Singh and Singh, 1987; Anderson, 1991; Kumar and Ram, 2005). However, Thandani and Ashton, (1995) reported that moderate disturbance in oak forest provide light to understory vegetation which also enables seedlings to grow on forest floor. The problem of insufficient regeneration of Kharsu Oak has also been reported by Singh and Singh (1992) and Vetaas (2000).

Altitudinal variation in dispersion pattern: Distribution pattern of most of the tree species was clumped (contagious) whereas shrub and herb species showed clumped as well as random distribution in the forest site and regular distribution was completely absent. Odum (1971) suggested that clumped distribution is the general pattern in nature whereas random distribution is mainly found in uniform environment and regular distribution pattern occurs where severe competition occurs between individuals. Dominance diversity curves were drawn on the basis of IVI for trees and PV for shrubs and herbs, which indicates that *Q. semecarpifolia* showed clear cut dominance at all the three sites in tree layer while the shrub layer showed almost equal share and in herb layer one species showed clear dominance (Fig. 5). Species richness has been used to assess species composition similarities among three forest stands (Table 5). In tree and shrub layer composition, LA and MA were more similar as compared to LA, while in herb layer composition HA showed more similarity with LA and MA.

Altitudinal variation in species diversity: The values of species richness (SR), forest stand density (D), total basal area (TBA), Shannon index (H'), Simpson diversity index (Cd) and Evenness index (E) were different in different altitudes (Table 3, 4). Seedling diversity was higher (2.075) than the value (0.64 to 1.27) reported by Bargali *et al.* (2011), while the reported value of Cd (0.624) falls within the range (0.05 to 0.76) reported by Bargali *et al.* (2011). Tree and sapling richness decreased with increasing altitude while shrub species richness increased (Table 3). Herb

Table 1: Importance Value Index (IVI) of tree and saplings and Provenance Value (PV) of seedlings

	Trees			Saplings			Seedlings		
Species	**LA**	**MA**	**HA**	**LA**	**MA**	**HA**	**LA**	**MA**	**HA**
Cedrus deodara (Roxb. Ex D. Don) G. Don	-	16.79	-	48.9	38.5	-	-	75	-
Cupressus torulosa D. Don	41.68	27.94	-	-	-	-	-	-	-
Litsea umbrosa Ness	-	-	-	41.14	-	-	-	-	-
Quercus floribunda Lindl. Ex. A Camus	21.02	-	-	-	-	-	-	-	-
Quercus lanuginosa D. Don	17.15	-	-	-	-	-	-	-	-
Quercus semecarpifolia Smith	220.14	255.22	286.23	209.23	261.45	219.46	-	125	-
Rhododendron arboreum Smith	-	-	13.77	-	-	80.53	-	-	-

Table 2: Altitudinal variation in Provenance Value (PV) of Shrubs and Herbs in *Q. semecarpifolia* forest

Species	**Family**		**PV**			**A/F**	
Shrub Layer		**LA**	**MA**	**HA**	**LA**	**MA**	**HA**
Berberis chitria Buch Ham. Ex Lindl.	Berberidaceae	67.82	89.36	63.64	0.17	0.25	0.30
Desmodium elegans DC.	Fabaceae	59.36	61.02	44.99	0.21	0.23	0.35
Rosa macrophylla Lindl.	Rosaceae	72.82	49.61	35.93	0.30	0.36	0.75
Viburnum cotinifolium D. Don	Adoxaceae	-	-	55.43	-	-	0.22
Herb Layer							
Ainsliaea aptera DC	Asteraceae	3.81	9.41	6.29	0.08	0.04	0.10
Anaphalis margaritacea L.	Asteraceae	-	-	11.78	-	-	0.24
Apluda mutica L.	Poaceae	83.79	42.81	37.12	0.32	0.18	0.34
Artemisia annua Linn.	Asteraceae	0.81	-	11.74	0.66	-	0.08
Arthraxon spp.	Poaceae	11.47	-	-	0.51	-	-
Athyrium schimperi Moug. Ex Fee. Mem. Foug	Athyriaceae	5.94	13.88	5.07	-	0.10	0.11
Dryopteris cochleata D. Don	Dryopteridaceae	1.54	-	3.32	0.23	-	0.23
Erigeron bellidiodes L.	Asteraceae	2.35	-	-	0.17	-	-
Geranium ocellatum Jacquem ex. Cambess.	Geraniaceae	6.82	4.96	5.25	0.09	0.07	0.12
Hedychium spicatum Sm.	Zingiberaceae	-	2.54	2.61	-	0.16	0.10
Onychium cryptogrammoides H. Christ	Cryptogrammaceae	1.71	2.79	1.74	0.375	0.23	0.06
Paspalum spp.	Poaceae	12.36	34.98	5.83	0.042	0.38	1.87
Pimpenella spp.	Apiaceae	14.72	8.52	6.47	0.034	0.05	0.11
Polygonum nepalense Meisn.	Polygonaceae	17.9	24.41	19.78	0.069	0.04	0.04
Roscocea purpurea Sm.	Zingiberaceae	2.27	2.29	1.92	0.133	0.10	0.23
Scutelaria lateriflora L.	Lamiaceae	1.96	2.54	16.48	0.600	0.16	0.07
Synotis penninervis DC	Asteraceae	12.58	23.97	14.16	0.031	0.02	0.04
Vallisneria wallichiana L.	Hydrocharitaceae	13.17	22.82	40.79	0.101	0.08	0.06
Viola odorata L.	Violaceae	5.86	4.07	4.88	0.097	0.08	0.09
Vitis himalayana Brandis	Vitaceae	0.89	-	4.71	0.900	-	0.08

species richness decreased from LA to MA and then increased in HA. A common pattern of monotonic declination in species richness against increasing altitude has been described by Stevenson (1994). High mountain climate effect is the reason of such declination as already reported by (Sharma *et al.,* 2014) from Garhwal Himalaya. Principal component analysis (PCA) correlation variance of trees, shrubs and herbs of species diversity, richness, biomass, showed Principal component 1 accounting for 60.97% (Eigen value = 3.66) and Principal component 2 accounting for 29.52% (Eigen value = 1.77) of the total explained variance in relation to altitude (Fig. 4 A). The PCA has confirmed that MA and HA with all plant stages have higher diversity index, dominance index, and evenness index.

Biomass and Carbon stock: The forest biomass ranged from 871.49 to 1050.17 t ha^{-1} of which maximum biomass (94.2%) was contributed by *Q. semecarpifolia* (Table 6). The tree biomass was maximum at HA (1050.17 t ha^{-1}) and minimum at MA (871.49 t ha^{-1}) while the sapling biomass was maximum at MA (32.56 t ha^{-1}) and minimum at HA (10.30 t ha^{-1}). At all the sites, *Q. semecarpifolia* contributed maximum biomass while *L. umbrosa* contributed minimum biomass (Table 7). The forest biomass and carbon stock

Table 3: Ecological indices of tree, sapling, seedling, shrub and herb layer in *Q. semecarpifolia* forest

Site		No. of species	Density (individuals ha^{-1})	TBA (m^2 ha^{-1})	H'	Cd	E
	Trees	4	910	80.8	2.465	0.743	1.767
	Saplings	3	70	0.307	1.827	0.55	1.663
LA	Seedlings	-	-	-	-	-	-
	Shrub	3	1040	-	1.286	0.386	1.171
	Herb	18	1588500	-	1.509	0.452	0.522
	Trees	3	850	76.55	2.875	0.865	2.615
	Saplings	2	220	0.597	2.33	0.702	3.361
MA	Seedlings	2	40	-	2.075	0.624	2.994
	Shrub	3	1300	-	1.21	0.363	1.101
	Herb	14	1075700	-	0.642	0.193	0.243
	Trees	2	1000	90.03	3.191	0.96	4.603
	Sapling	2	60	0.225	2.396	0.697	3.457
HA	Seedling	-	-	-	-	-	-
	Shrub	4	1460	-	0.859	0.258	0.62
	Herb	18	750400	-	0.526	0.153	0.181

Where H': diversity index; Cd: dominance index; E: evenness index; TBA: total basal area

Table 4: Correlation analysis of different diversity indices

	Altitude	Vegetation	Density	SR	TBA	H'	Cd	E
Altitude	1.00							
Vegetation	0.00	1.00						
Density	-0.14	**0.670****	1.00					
SR	0.02	**-0.707****	-0.24	1.00				
TBA	-0.03	**0.566***	**0.792****	-0.15	1.00			
H	-0.01	**-0.720****	-0.26	**0.671****	-0.14	1.00		
Cd	-0.02	**-0.721****	-0.26	**0.677****	-0.14	**1.000****	1.00	
E	0.22	**-0.721****	-0.42	0.51	-0.34	**0.905****	**0.902****	1.00

*: Significant at < 5% level of significance; **: significant at < 1% level of significance; TBA: total basal area; SR: species richness; H': diversity index; Cd: dominance index; E: evenness index; Vegetation indicates trees, shrubs and herbs

Table 5: Percent Similarity Index (%) between the sites

	Altitudes	Low altitude	Mid altitude	High altitude
Trees	LA	100	66.66	44.44
	MA		100	66.66
	HA			100
Shrubs	LA	100	100	85.71
	MA		100	85.71
	HA			100
Herbs	LA	100	81.25	88.88
	MA		100	87.50
	HA			100

values were higher than the values reported by Rawat and Singh, (1988) indicating that these forests are still growing at moderate rate but are anthropogenically disturbed. Tree carbon stock was maximum at HA while minimum carbon stock was reported at MA. Total carbon stock of saplings was highest (32.56 t ha^{-1}) at MA and minimum (10.30 t ha^{-1}) at LA. The total biomass of the herb layer ranged from 418.9 gm^{-2} to 505.15 gm^{-2} (Table 8). At LA, *A. mutica* contributed highest biomass (153.17 gm^{-2}). The total herb layer biomass at MA was 418.9 gm^{-2} of which 63.03% was aboveground and 36.96% was belowground. *Synotis*

Table 6: Altitudinal variation in biomass (t ha^{-1}) and carbon stock (t ha^{-1}) of tree layer

Site	Species	Bole	Bole bark	Branches	Twigs	Foliage	Stump root	Lateral roots	Fine roots	Biomass	Carbon stock
	Q. semecarpifolia	435.22	38.36	113.08	18.51	15.05	117.68	51	19.91	808.81	384.184
	Q. floribunda	9.52	0.83	4.37	1.07	1	2.99	1.63	0.51	21.92	10.412
LA	*C. torulosa*	43.59	1.45	13.18	2.45	2.45	6.82	2.2	0.62	72.76	34.561
	Q. lanuginose	10.65	-	6.22	2.07	1.22	2.54	0.28	0.003	22.98	10.916
	Total	**498.98**	**40.64**	**136.85**	**24.1**	**19.72**	**130.03**	**55.11**	**21.043**	**926.47**	**440.077**
	Q. semecarpifolia	434.57	38.32	112.91	18.54	15.08	117.76	51.01	19.95	808.14	383.86
	C. torulosa	31.28	0.88	7.62	1.18	1.23	4.06	1.02	0.31	47.58	22.6
MA	*C. deodara*	10.1	0.52	1.95	0.65	0.45	1.48	0.56	0.06	15.77	7.49
	Total	**475.95**	**39.72**	**122.48**	**20.37**	**16.76**	**123.3**	**52.59**	**20.32**	**871.49**	**413.95**
	Q. semecarpifolia	563.12	49.62	146.32	23.79	19.33	151.6	65.76	25.6	1045.14	496.45
HA	*R. arboreum*	2.53	0.07	0.96	-	0.2	0.86	0.37	0.04	5.03	2.39
	Total	**565.65**	**49.69**	**147.28**	**23.79**	**19.53**	**152.46**	**66.13**	**25.64**	**1050.17**	**498.84**

Table 7: Altitudinal variation in biomass (t ha^{-1}) and carbon stock (t ha^{-1}) of sapling layer

Site	Species	Bole	Bole bark	Branches	Twigs	Foliage	Stump root	Lateral roots	Fine roots	Biomass	Carbon stock
LA	*Q. semecarpifolia*	5.640	0.500	1.460	0.340	0.290	1.930	0.790	0.360	11.310	5.372
	L. umbrosa	0.132	0.006	0.037	0.012	0.008	0.077	0.039	0.006	0.317	0.150
	C. deodara	0.058	0.003	0.072	0.076	0.057	0.056	0.059	0.008	0.389	0.184
	Total	**5.83**	**0.509**	**1.569**	**0.428**	**0.355**	**2.063**	**0.888**	**0.374**	**12.016**	**5.706**
MA	*Q. semecarpifolia*	15.63	1.400	4.05	1.01	0.86	5.57	2.28	1.07	31.870	15.138
	C. deodara	0.04	0.003	0.12	0.2	0.15	0.09	0.07	0.02	0.693	0.329
	Total	**15.67**	**1.403**	**4.17**	**1.21**	**1.01**	**5.66**	**2.35**	**1.09**	**32.563**	**15.467**
HA	*Q. semecarpifolia*	4.92	0.443	1.28	0.311	0.263	1.728	0.709	0.329	9.983	4.742
	C. deodara	0.038	0.002	0.057	0.068	0.051	0.044	0.052	0.008	0.320	0.152
	Total	**4.958**	**0.445**	**1.337**	**0.379**	**0.314**	**1.772**	**0.761**	**0.337**	**10.303**	**4.894**

penninervis contributed maximum biomass (178.98 gm^{-2}) while *Scutelaria lateriflora* showed minimum contribution (2.82 gm^{-2}). At HA, the total biomass was 441.65 gm^{-2}, highest of which was contributed by *Synotis penninervis* (150.79 gm^{-2}) and lowest by *Onychium cryptogrammoides* (2.32 gm^{-2}). The biomass values are similar to the earlier reports from the region (Karki *et al.,* 2017; Mourya *et al.,* 2019).

Physico-chemical properties of soil: The soil is clay loam in texture in all the studied sites. Variation in soil texture was recorded along the altitudinal gradient (Table 9). The physico-chemical properties of soil vary within space and time due to the variation in topography, climate, weathering processes, vegetation cover, microbial activities, season, and other biotic and abiotic factors, (Bargali *et al.,* 1993a and b; Bargali, 1996; Manral *et al.,* 2020; Karki *et al.,* 2021). Therefore, soil properties in the highly dissected landscape of Himalaya vary within short distances resulting in a pronounced heterogeneity of soils and their physico-chemical properties (Bargali *et al.,* 2018; Bargali *et al.,* 2019; Vibhuti *et al.,* 2020).

ANOVA on soil characteristics showed that the altitude had significant effect (Table 9, 10) on SMC, clay content and WHC ($p<0.05$). Pearson's correlation revealed with increasing altitude WHC, SMC, SOC and TN decreased whereas bD increased significantly. Low mineralization rate and net nitrification rate at higher altitude explains the decreasing trend of SOC (Bangroo *et al.,* 2017). In present study, decline in tree and shrub richness along altitudinal gradient was observed which may correspond to less accumulation of litter and low input of organic carbon in soils. The positive and significant correlation between C and N is mainly due to the concurrent release of carbon and nitrogen elements during nutrient decomposition by microorganism (Jiang *et al.,* 2019). Hence, there is a close relationship between soil nitrogen and carbon. Soil depth showed significant positive impact on bD while WHC, porosity, SOC and TN were negatively correlated (Appendix Table 1). The paired t-test comparison of mean measures of soil attributes between two depths (0–15 cm and 15–30 cm) at each altitude showed significant variation ($p < 0.05$) in SMC, WHC, porosity and TN. The bD and SOC did not vary significantly between depths (Table 10). The decomposition of organic matter takes place in the uppermost layers of the soil resulting in low nutrient content in sub-surface soil layers (Kewlani *et al.,* 2021). The different physical properties of soil assist to check the soil erosion and fertility (Sharma and Bhatia,

Table 8: Biomass of herb layer in *Q. semecarpifolia* forest stands

Species	Biomass (gm^{-2})					
	Above ground biomass			Below ground biomass		
	LA	MA	HA	LA	MA	HA
Ainsliaea aptera DC	2.38	10.01	5.84	0.96	5.04	2.67
Anaphalis margaritacea L.	-	-	28.42	-	-	9.38
Apluda mutica L	106.93	40.84	32.72	46.24	15.46	8.74
Artemisia annua Linn.	1.35	-	29.66	1.67	-	10.27
Arthraxon spp.	15.55	-	-	8.34	-	-
Athyrium schimperi Moug. Ex Fée. Mém. Foug	3.95	7.1	3.29	4.46	3.94	0.53
Dryopteris cochleata D. Don	3.44	-	2.98	1.81	-	1.52
Erigeron bellidiodes L.	1.8	-	-	0.55	-	-
Geranium ocellatum Jacquem ex. Cambess.	8.56	7.11	10.39	6.01	4.3	1.25
Hedychium spicatum Sm.	-	8.32	6.11	-	8.71	3.23
Onychium cryptogrammoides H. Christ	4.59	9.37	1.87	3.57	2.59	0.45
Paspalum spp.	23.08	16.67	4.9	14.71	7.56	2.26
Pimpenella spp.	11.15	7.47	2.91	34.27	18.58	16.86
Polygonum nepalense Meisn.	12.14	-	16.51	9.2	-	8.46
Roscocea purpurea Sm.	3.73	2.01	3.11	2.05	1.55	1.24
Scutelaria lateriflora L.	7.15	2.08	16.72	3.19	0.74	8.36
Synotis penninervis DC	68.96	114.54	99.11	55.29	64.44	51.68
Vallisneria wallichiana L.	8.45	15.29	22.69	4.63	8.7	12.66
Viola odorata L.	15.95	3.62	8.58	8.65	2.15	2.99
Vitis himalayana Brandis	0.15	-	2.19	0.15	-	1.02

Table 9: Physico-chemical properties of soil

Altitude	Depth (cm)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	SMC	Porosity	WHC	Bulk density	pH	SOC (%)	TN (%)
LA	0-15	44.05 ±2.88	20.6 ±0.92	23.39 ±0.11	11.39 ±1.71	34.09 ±1.15	65.72 ±0.69	80.2 ±2.80	0.891 ±0.01	5.66 ±0.08	3.08 ±0.01	0.45 ±0.12
	15-30	53.43 ±1.67	16.97 ±0.35	19.52 ±0.52	9.8 ±1.13	32.51 ±1.62	62.07 ±1.31	72.02 ±1.73	0.986 ±0.03	5.76 ±0.06	2.14 ±0.02	0.32 ±0.06
MA	0-15	44.7 ±1.90	19.93 ±1.35	23.39 ±2.76	11.35 ±2.02	28.18 ±2.64	62.99 ±2.71	79.44 ±1.56	0.962 ±0.07	5.86 ±0.03	2.94 ±0.02	0.32 ±0.06
	15-30	47.11 ±1.34	20.41 ±0.42	20.09 ±1.33	12.37 ±1.67	26.29 ±1.51	57.7 ±0.43	65.72 ±3.06	1.09 ±0.01	5.76 ±0.03	1.95 ±0.01	0.21 ±0.08
HA	0-15	51.5 ±1.85	17.52 ±3.08	20.04 ±2.30	9.58 ±3.31	28.57 ±1.66	61.29 ±2.32	74.47 ±0.95	1.006 ±0.06	5.76 ±0.06	2.11 ±0.01	0.22 ±0.06
	15-30	54.66 ±1.83	18.18 ±3.53	17.8 ±1.21	9.33 ±2.40	28.01 ±0.65	57.44 ±1.18	63.58 ±0.83	1.102 ±0.005	5.83 ±0.06	1.24 ±0.02	0.18 ±0.05

Table 10: ANOVA (Analysis of Variance) for soil parameters

	SMC	Gravel %	Sand %	Silt %	Clay %	pH	WHC	bD	Porosity	SOC	TN
Altitude	62.82*	65.21^{ns}	7.76^{ns}	7.44^{ns}	6.95*	0.017^{ns}	289.74**	0.22^{ns}	33.58^{ns}	1.49*	0.053**
Soil depth	8.44^{ns}	80.89^{ns}	14.41^{ns}	15.34^{ns}	0.29^{ns}	0.002^{ns}	236.38*	0.05*	79.42*	3.92**	0.040*

*: Significant at < 5% level of significance, ** Significant at < 1% level of significance; ns: not significant, FW: fresh weight of soil, DW: dry weight of soil, SMC: soil moisture content, WHC: water holding capacity, bD: bulk density, SOC: soil organic carbon, TN: total Nitrogen.

2003). The PCA of soil physico-chemical attributes revealed Principal component 1 accounting 52.44% (Eigen value = 7.34) and Principal component 2 accounting 23.89% variance (Eigen value = 3.34). PCA confirmed LA and MA had higher SOC, TN, WHC and SMC (Fig. 4 B). Pearson's correlation among altitude, tree richness (TR), shrub richness (SR), herb richness (HR), and

Appendix Table 1: Correlation analysis of different soil parameters with altitude and species richness.

	Altitude	Depth	SMC	Gravel	Sand	Silt	Clay	pH	WHC	bD	Porosity	SOC	TN	TR	SR	HR
Altitude	1															
Depth	0	1														
SMC	-0.56*	-0.19	1													
Gravel	0.32	0.407	-0.09	1												
Sand	-0.22	-0.458	0.00	-0.97**	1											
Silt	-0.23	-0.446	0.04	-0.97**	0.96**	1										
Clay	-0.38	-0.088	-0.05	-0.82**	0.75**	0.73**	1									
pH	0.33	0.108	-0.18	0.23	-0.19	-0.21	-0.32	1								
WHC	-0.72**	-0.49*	0.65**	-0.41	0.36	0.35	0.27	-0.26	1							
bD	0.49*	0.56*	-0.74**	0.29	-0.24	-0.28	-0.12	-0.05	-0.71**	1						
Porosity	-0.49*	-0.56*	0.74**	-0.3	0.24	0.28	0.12	0.04	0.72**	-1.00**	1					
SOC	-0.62**	-0.75**	0.38	-0.59*	0.56*	0.55*	0.40	-0.21	0.81**	-0.69**	0.69**	1				
TN	-0.81**	-0.51*	0.61**	-0.42	0.37	0.37	0.32	-0.42	0.86**	-0.69**	0.70**	0.85**	1			
TR	-1.00**	0	0.56*	-0.32	0.21	0.23	0.38	-0.33	0.76**	-0.49*	0.49*	0.62**	0.81**	1		
SR	0.86**	0	-0.25	0.48*	-0.39	-0.39	-.57*	0.15	-0.57*	0.34	-0.34	-0.65**	-0.63**	-0.87**	1	
HR	0	0	0.47	0.41	-0.43	-0.37	-.47*	-0.26	0.16	-0.16	0.17	-0.23	0.15	0	0.50*	1

*: Significant at < 5% level of significance; **: significant at < 1% level of significance; FW: fresh weight, DW: dry weight, SMC: soil moisture content, WHC: water holding capacity, bD: bulk density, SOC: soil organic carbon, TN: total Nitrogen, TR: tree richness, SR: shrub richness, HR= herb richness.

soil nutrients revealed that most of the parameters were significantly correlated with the altitude (Appendix Table 1).

TR showed significant negative correlation with altitude while SR showed positive correlation (p<0.01). Physico-chemical parameters of soil are governed by the parent material and weathering processes of parent rocks, hence affecting the structure and functioning of the vegetation type. All these factors (altitude, soil conditions as well as anthropogenic pressure) collectively affect the vegetation pattern. It was concluded from the study that the regeneration status of the *Q. semecarpifolia* forest was poor as there were negligible seedlings as compared to adult trees. The regeneration has decreased as oak seedlings have a slim chance of survival in the dense shade, as among thousands of acorns only few survive up to seedling stage and only few of them grow to a fully matured tree. If this condition continues, not only this high altitudinal species will be imperiled, but also the flora and fauna which directly or indirectly depends on this species will get affected in the near future, ultimately leading to serious ecological imbalance. Thus, strategy should be adopted for proper management and conservation of *Q. semecarpifolia* forests in Himalaya.

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