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Plant Diversity, Tree Regeneration, Biomass Production and Carbon Storage in Different Oak Forests on Ridge Tops of Garhwal Himalaya

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Abstract

The present study was conducted on ridge tops of moist temperate Oak forests in Garhwal Himalaya to assess the plant diversity, regeneration, biomass production and carbon assimilation in different Oak forests. For this purpose, three Oak forest types viz., (a) *Quercus leucotrichophora* or Banj Oak (FT1; between 1,428-2,578 m asl), (b) *Quercus floribunda* or Moru Oak (FT2; between 2,430-2,697 m asl) and (c) *Quercus semecarpifolia* or Kharsu Oak (FT3; between 2,418-3,540 m asl) were selected on different ridge tops in Bhagirathi catchment area of Garhwal Himalaya. A total of 91 plant species including 23 trees (8 gymnosperms and 15 angiosperms), 21 shrubs and 47 herbs species belonging to 46 families were recorded from all the ridge top Oak forests. The highest mean tree density (607±33.60 trees ha^{-1}) was observed in *Q. floribunda* forest with lower mean total basal cover (TBC) value (48.02±3.67 m^2ha^{-1}), whereas highest TBC value (80.16±3.30 m^2ha^{-1}) was recorded for *Q. semecarpifolia* forest, with lowest mean stem density (594±23.43 stems ha^{-1}). The total biomass density (TBD) across three Oak forests ranged between 497.32±83.70 (FT1) and 663.16±93.85 t ha^{-1} (FT3), while the total carbon density (TCD) values ranged between 228.75±22.27 (FT1) and 304.31±18.12 t ha^{-1} (FT3). Most of the tree species were found with good regeneration (GR) status (average 45%) in all the forest types whereas, few species were found not regenerating (NR) (average 17%) however, few new recruitments were also recorded. ANOVA (Post-Hoc Tukey's test at 5% significance level) indicated significant forest-wise differences in TBC, TBD and TCD (in tree layer); family and evenness (in shrub layer only) values, while insignificant differences were noticed in density values of tree, seedling and herb layer.

Key Words: Garhwal Himalaya, moist temperate, ridge top forests, diversity and regeneration, biomass and carbon

Introduction

The Oaks are the keystone species of Himalayan forest ecosystems, without which the complex web of rural livelihood cannot be imagined. Oaks are multipurpose tree species, which are closely linked with hill agriculture as an important source of fodder, firewood and making compost by litter. The regeneration of Oak forests in Himalayan region is reported to be steadily deteriorating (Singh and Singh 1992). The causes of failure of regeneration include lack of production of viable seeds, insect and animal predation, unfavourable micro-sites, overgrazing by domestic animals, habitat change and biological invasions. Thus for proper management of Himalayan Oak forests, the knowledge on diversity, population structure, distribution, regeneration, stocking, biomass production and carbon storage is necessary to support the conservation and restoration of Oak species.

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In Garhwal Himalaya mainly three Oak species are dominant on different altitudes i.e., (i) *Quercus semecarpifolia* Sm. (Kharsu Oak/Brown Oak), which is found in upper altitudinal zones (between 2,418-3,540 m asl), (ii) *Quercus floribunda* Lindle. (Moru Oak/Green Oak) in the middle zones (between 2,430-2,697 m asl) and (iii) *Quercus leucotrichophora* A. Camus. (Banj Oak/White Oak) in the lower altitudinal zones (between 1,428-2,578 m asl).

Understanding the forest structure is a pre-requisite to describe various ecological processes and also to model the functioning and dynamics of forests (Elourad et al. 1997). The nature of forest communities largely depends on the ecological characteristics of sites, species diversity and regeneration status of species. Micro-environmental factors affect the growth stages i.e., seedling, sapling and young trees of the forest communities that maintain the population structure of any forest. Regeneration of species is critical in a forest, because it decides the desired species composition and stocking in future. Regeneration of any species is confined to a peculiar range of habitat conditions and the extent of those conditions is a major determinant of its geographical distribution.

Climate controls the distribution of vegetation (Vetaas 2000) and future changes in climate are projected to cause changes in the vegetation distribution ranges. Several studies have attributed widespread changes in plant growth or mortality to climate change, but these efforts were focused on general trends within a biome rather than identifying spatially coherent distribution pattern (Pauli et al. 2007; Engler et al. 2009).

The Himalayan ridge top (RT) 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 places 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 tops. It is understandable, because the recent global warming has resulted in disturbances of ecological relationships, alteration in plant life history and general upward shift in the species distributional ranges (Mc Kone et al. 1998; Klanderud 2005; Jaurasinski and Kreyling 2007; Pauli et al. 2012).

The carbon storage in forest ecosystems is strongly affected by climate, forest type, stand age, disturbance regimes and edaphic conditions (Pregitzer and Euskirchen 2004). Climate change can modify the tree species composition and migration patterns (Bu et al. 2008), which can further influence the forest composition. Thus the forest carbon is a useful measure for the assessment of changes in forest structure and composition. Biomass production and carbon stock will reveal the carbon sequestration potential by Oaks at high mountains. In this study the specific questions, we tried to answer were (i) the structure, composition, diversity and regeneration status of different Oak forests on ridge tops, and (ii) biomass and carbon storage potential of Oak species on ridge tops at various altitudes.

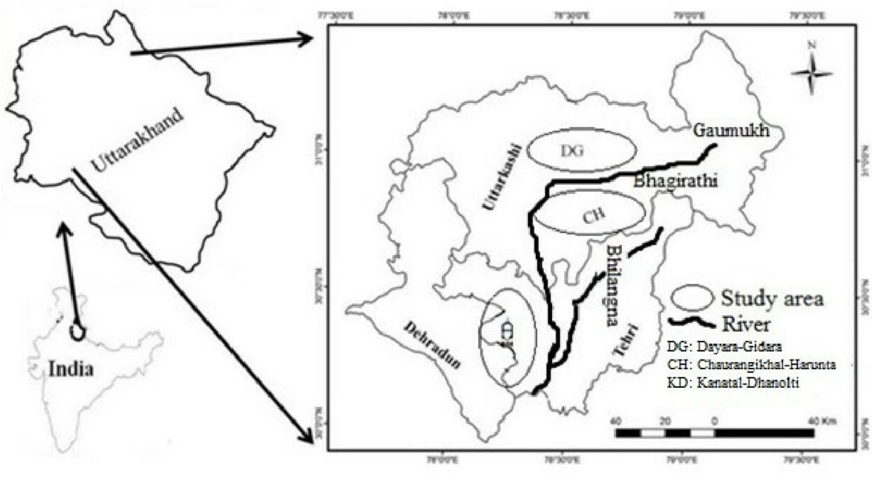

Fig. 1. Map representing the study sites.

Materials and Methods

Study area

This study was conducted in the moist temperate forests of Bhagirathi Catchment area in Garhwal Himalaya. A reconnaissance survey of the study area was done from June to February in the years 2014 and 2015. The study area lies in two different districts (Uttarkashi and Tehri) of Uttarakhand state. We have selected 30 ridge tops of Oak dominated forests, in which *Quercus leucotrichophora* forest (FT1) was situated at 30°07'50.8"N latitude and 078° 17'10.5"E longitude; *Quercus floribunda* forest (FT2) at 30°24'0.6"N latitude and 078°28'39.1"E longitude; and *Quercus semecarpifolia* forest (FT3) at 30°39'12.9"N latitude and 078°39'45.2"E longitude. The climate of the entire study area was moist temperate type with mean minimum monthly temperature ranging from 7.12°C (Jan) to 23.20°C (Jul) and mean maximum monthly temperature from 17.56°C (Jan) to 33.35°C (Jul) (Suyal et al. 2010), however, mean annual rainfall was amounted as 2000 mm. There were three main distinct seasons in a year *i.e*., cool and relatively dry winter (December to March); the warm and dry summer (mid-April to June); and a warm and wet period (July to mid-September) called as the monsoon or rainy season. These regions contain varying topographical features ranging from snow free valleys to the high peaks with perpetual snow and glaciers (Fig. 1).

Vegetation analysis

For quantitative analysis of forest vegetation and regeneration pattern on ridge tops of different Oak forest types, ten sample plots of 0.1 ha, each were randomly laid out on surveyed ridge tops in each forest type to analyse the tree species (10 sample plots×03 forest types=30 sample plots). Within each 0.1 ha sample plot, 5 m×5 m sized quadrats were laid out randomly to analyse the tree saplings and shrubs. However, 1 m×1 m sized quadrats were used for the analysis of tree seedlings and herbs (Curtis and McIntosh 1950; Phillips 1959). Circumference at breast height (cbh at 1.37 m from the ground) was taken for the determination of tree basal cover. The quantitative parameters of the community, i.e., frequency, density, total basal cover and IVI were calculated following Cottam and Curtis (1956). On the basis of data so obtained the Shannon-Wiener diversity Index (Shannon and Weaver 1963), Simpson dominance Index (Simpson 1949), evenness (Pielou 1966) and β-diversity (Whittaker 1972) were also computed. However, the Index of similarity (IS) between forest types was calculated following Muller-Dombois and Ellenberg (1974) as: Similarity index $=\frac{2C}{A+B}\times 100$, Where C is the number of common species shared between compared forest types and A and B are the number of species in each forest respectively.

Population structure and regeneration pattern

To determine the population structure and regeneration pattern in each forest type the dbh classes were established on the basis of range of available data. The tree (0.1 ha), sapling (5 m×5 m) and seedling (1 m×1 m) densities were calculated and extrapolated on per hectare basis. Different regeneration categories (Good, Fair, Poor, Not and New regeneration) were created to express the regeneration status in the forest. Regeneration of woody plant species was determined based on population size of seedlings, saplings and adults and categorized as per Khumbongmayum et al. (2006).

Biomass and carbon

The biomass for tree components was estimated using the linear regression equation framed out by Rawat and Singh (1988) and Adhikari et al. (1998) as: ln Y=a+b ln X; Where ln=natural log, Y=dry weight of component (kg), X=CBH (cm), a=the y-intercept and b=slope of regression. The carbon % for different forest types was calculated as per Sharma et al. (2010). We used the inter-species regression equation (Rawat and Singh 1988) for those species which are not independently mentioned.

The identification of plants was done with the help of existing taxonomic literature, described in Flora of Gangotri National Park (Pusalkar and Singh 2012), Flora of the district Garhwal North West Himalaya (Gaur 1999) and Herbarium of H.N.B. Garhwal University Srinagar (GUH).

Statistical analysis

ANOVA (Post-Hoc tukey's test) for different ecological attributes was performed by using SPSS (version-22).

Table 1. Ecological indices of trees, shrubs, herbs and statistical results (ANOVA) in different ridge Oak forests of high mountain

Stages	FTs	SR	Genus	Family	C_d	$\overline{H}$	e	Den	TBC	TBD	TCD	Similarity%	β-diversity
Trees	FT1	08	07	05	0.39	0.58	0.28	603	69.94	497.32	228.75		
	FT2	12	10	07	0.45	0.55	0.22	607	48.02	576.71	265.15	44.64	1.64
	FT3	14	12	08	0.43	0.62	0.23	594	80.16	663.16	304.31		
	F value	0.318	0.358	0.620	0.064	0.096	1.100	0.046	12.765	5.990	5.990		
	p value	0.730	0.702	0.545	0.938	0.909	0.347	0.955	0.000	0.007	0.007		
Saplings	FT1	07	06	05	0.29	0.67	0.34	1,874	1.11	-	-		
	FT2	11	10	07	0.22	0.82	0.34	2,787	0.37	-	-	27.73	2.63
	FT3	10	09	06	0.20	0.83	0.36	2,133	0.69	-	-		
	F value	0.507	0.600	1.315	0.866	0.561	1.216	4.535	3.045				
	p value	0.608	0.555	0.284	0.432	0.577	0.312	0.020	0.064				
Seedlings	FT1	07	06	05	0.29	0.69	0.35	30,571	-	-	-		
	FT2	09	07	06	0.25	0.75	0.34	38,667	-	-	-	49.58	1.17
	FT3	08	07	06	0.24	0.75	0.36	46,167	-	-	-		
	F value	0.309	0.292	0.580	0.987	0.591	0.869	3.033					
	p value	0.736	0.744	0.566	0.385	0.561	0.430	0.064					
Shrubs	FT1	14	14	11	0.11	1.06	0.40	3,303	-	-	-		
	FT2	12	12	10	0.09	1.07	0.43	3,000	-	-	-	53.05	1.05
	FT3	10	10	08	0.12	0.96	0.42	3,867	-	-	-		
	F value	1.662	1.662	4.253	0.728	0.845	9.165	3.499					
	p value	0.208	0.208	0.024	0.492	0.440	0.001	0.044					
Herbs	FT1	23	23	15	0.05	1.32	0.42	142,571	-	-	-		
	FT2	23	23	16	0.06	1.3	0.42	145,833	-	-	-	32.64	2.24
	FT3	19	19	13	0.07	1.23	0.42	140,833	-	-	-		
	F value	0.210	0.210	0.413	0.243	0.037	1.360	0.067					
	p value	0.811	0.811	0.666	0.786	0.964	0.273	0.935					

FTs, forest types; FT1, forest type1; FT2, forest type2; FT3, forest type3; SR, species richness; C_d, Simpson index; $\overline{H}$, Shannon Index; e, Pielou evenness index; Density (ind ha^{-1}); TBC (m^2 ha^{-1}); TBD (Mg ha^{-1}); TCD (t C ha^{-1}).

Results and Discussion

Forest structure and species composition

After systematic survey of Oak forests on the ridge tops of Bhagirathi catchment area, total 91 plant species belonging to 81 genera and 46 families were recorded. In *Q. leucotrichophora* forest, 45 species (08 trees, 14 shrubs and 23 herbs); in *Q. floribunda* forest, 47 species (12 trees, 12 shrubs and 23 herbs); and in *Q. semecarpifolia* forest, 43 species (14 trees, 10 shrubs and 19 herbs) were recorded. No significant variation was found in species richness, genus and families (except understorey shrub layer) in selected oak forest types (Table 1).

Tree species like *Abies pindrow, A. spectabilis, Lyonia ovalifolia, Rhododendron arboreum Ilex dipyrena* etc. were dominant/co-dominant species which formed the established association with oak forests on high mountain ridge tops of Western Himalaya. Consequently, in this study *Rhododendron arboreum* and *Lyonia ovalifolia* were found widely distributed in all *Quercus* forest types as co-dominant species. Whereas, *Abies pindrow, Ilex dipyrena* and *Symplocos paniculata* were co-dominants in *Q. floribunda* and *Q. semecarpifolia* forests only. In FT1, the *Q. leucotrichophora* (430 trees ha^{-1}), *R. arboreum* (66 tree ha^{-1}) and *Q. floribunda* (47 tree ha^{-1}) together constituted 90% of the total forest density, which was greater than the previous recorded density by Singh and Rawat (2012) for Banj Oak forest. Similarly in FT2, the *Q. floribunda* (453 trees ha^{-1}), *R. arboreum* (99 trees ha^{-1}) and *L. ovalifolia* (13 tree ha^{-1}) together constituted 93% of the total forest density. In FT3, the *Q. semecarpifolia* (430 trees ha^{-1}) and *R. arboreum* (57 trees ha^{-1}) together contributed 81% of the total forest density. These values were similar to the values reported by Singh and Rawat (2012). The mean tree density in these forests ranged from 594±23.43 (FT3) to 607±33.60 individuals ha^{-1} (FT2), whereas mean Total Basal Cover values oscillated from 48.02±3.67 (FT2) to 80.16±3.30 m^2 ha^{-1} (FT3). The earlier reported values of density and TBC in *Q. leucotrichophora* forest were 790-1,260 individual ha^{-1} and 13.60-71.25 m^2 ha^{-1} (Kusumlata and Bisht 1991), 554 trees ha^{-1} and 39.20 m^2 ha^{-1} (Thadani and Ashton 1995), 100-860 trees ha^{-1} and 8.42-59.71 m^2 ha^{-1} (Sharma et al. 2001), 730 ind ha^{-1} and 43.96 m^2 ha^{-1} (Srivastava et al. 2005), 990 trees ha^{-1} and 35.08 m^2 ha^{-1} (Gairola et al. 2011), 433 trees ha^{-1} and 88.06 m^2 ha^{-1} (Singh and Rawat 2012), 400-933 trees ha^{-1} and 14.22-40.16 m^2 ha^{-1} (Rawal et al. 2012). In *Q. floribunda* forest the reported values of density and TBC were 220-640 individuals ha^{-1} and 23.53 to 43.24 m^2 ha^{-1} (Sharma et al. 2001), 493 individuals ha^{-1} and 72.51 m^2 ha^{-1} (Gairola et al. 2012), 433 trees ha^{-1} and 110.47 m^2 ha^{-1} (Singh and Rawat 2012), 423-793 trees ha^{-1} and 11.20-34.01 m^2 ha^{-1} (Rawal et al. 2012), 620 trees ha^{-1} and 103.98 m^2 ha^{-1} (Bisht et al. 2013). Similarly in *Q. semecarpifolia* forest the density and TBC values were found ranging between 340-810 trees ha^{-1} and 30.1-62.2 m^2 ha^{-1} (Rai et al. 2012), 600 trees ha^{-1} and 58.25 m^2 ha^{-1} (Gairola et al. 2012), 337 trees ha^{-1} and 90.16 m^2 ha^{-1} (Singh and Rawat 2012), 407-723 trees ha^{-1} and 54.84-69.75 m^2 ha^{-1} (Rawal et al. 2012), 340 trees ha^{-1} and 48.51 m^2 ha^{-1} (Bisht et al. 2013). Joshi and Yadava (2015) have also reported high range of tree density (765-1000 tree ha^{-1}) and TBC (56.96-88.88 m^2 ha^{-1}) for various Oak forests of Kumaun Himalayan region.

The TBC values were greater in *Q. semecarpifolia* forest at higher altitudes (2,418-3,540 m asl) because these were the mature/less disturbed forests and consequently shown higher productivity. However, lower altitudinal *Q. leucotrichophora* forests (1,428-2,578 m asl) have reflected moderate density and TBC values, because they were situated close to human settlement. There was no significant variation ($F=0.046$, $p=0.955$) between overall tree density values in different Oak forests, whereas highly significant difference ($F=12.764$, $p=0.0001$) was observed between TBC values in all the three oak forest types. The other statistical values (ANOVA) of overstorey and understorey vegetation for various ecological variables/parameters are given in Table 1. The tree seedling density in this study was recorded in the range of 30571 (FT1) to 46167 seedlings ha^{-1} (FT3). Rawal et al. (2012) have reported 5,800-13,200 seedlings ha^{-1} (*Q. leucotrichophora* forest), 10,133-21,867 seedlings ha^{-1} (*Q. floribunda* forest), and 267-933 seedlings ha^{-1} (*Q. semecarpifolia* forest) in various Oak forests. Greater tree density (607 trees ha^{-1}) and sapling density (2,787 saplings ha^{-1}) in FT2 (between 2,430-2,697 m asl) have indicated good regeneration and growth of species in moderate environmental conditions. Mild disturbance has also been reported to provide greater opportunities for species turnover, established colonization and persistence of

Table 2. Density (plant/100 m^2) and importance value index (IVI) of important species in different oak forests

S.N.	Species	Family	FT1		FT2		FT3	
			Density	IVI	Density	IVI	Density	IVI
1.	*Abies pindrow*	Pinaceae	-	-	0.08	7.10	0.28	22.56
2.	*Abies spectabilis*	Pinaceae	-	-	-	-	0.27	13.91
3.	*Acer acuminatum*	Aceraceae	-	-	-	-	0.02	1.29
4.	*Alnus nepalensis*	Betulaceae	0.07	4.28	-	-	-	-
5.	*Betula alnoides*	Betulaceae	0.09	5.94	0.01	1.06	-	-
6.	*Betula utilis*	Betulaceae	-	-	-	-	0.09	5.47
7.	*Cedrus deodara*	Pinaceae	-	-	0.05	5.28	-	-
8.	*Cupressus torulosa*	Cupressaceae	-	-	0.01	1.00	-	-
9.	*Ilex dipyrena*	Aquifoliaceae	-	-	0.075	6.47	0.11	7.92
10.	*Lyonia ovalifolia*	Ericaceae	0.3	22.82	0.13	10.98	0.02	2.08
11.	*Neolitsea cuipala*	Lauraceae	-	-	0.03	3.29	-	-
12.	*Neolitsea pallens*	Lauraceae	-	-	0.05	3.67	-	-
13.	*Picea smithiana*	Pinaceae	-	-	-	-	0.08	6.18
14.	*Pinus roxburghii*	Pinaceae	0.09	8.94	-	-	-	-
15.	*Pinus wallichiana*	Pinaceae	-	-	-	-	0.07	5.94
16.	*Pyrus pashia*	Rosaceae	0.06	5.02	-	-	-	-
17.	*Quercus floribunda*	Fagaceae	0.47	34.25	4.53	191.58	0.03	2.87
18.	*Quercus leucotrichophora*	Fagaceae	4.3	177.56	0.05	5.96	-	-
19.	*Quercus semecarpifolia*	Fagaceae	-	-	-	-	4.3	191.58
20.	*Rhododendron arboreum*	Ericaceae	0.66	41.18	0.99	58.55	0.57	31.02
21.	*Sorbus cuspidata*	Rosaceae	-	-	-	-	0.04	3.20
22.	*Symplocos paniculata*	Symplocaceae	-	-	0.07	5.07	0.03	2.51
23.	*Taxus wallichiana*	Taxaceae	-	-	-	-	0.04	3.46
	Shrubs							
1.	*Berberis aristata*	Berberidaceae	2.29	23.07	4	34.75	7.87	51.72
2.	*Colebrookia oppositifolia*	Lamiaceae	0.57	9.31	-	-	1.27	16.27
3.	*Cotoneaster microphyllus*	Rosaceae	1.03	14.22	2.73	26.43	3.53	28.47
4.	*Daphne papyracea*	Thymelaeaceae	-	-	2.6	25.62	3	26.71
5.	*Desmodium elegans*	Fabaceae	1.49	17.02	-	-	-	-
6.	*Elsholtzia flava*	Lamiaceae	0.91	12.99	1.8	20.09	-	-
7.	*Eupatorium adenophorum*	Asteraceae	10.63	66.11	-	-	-	-
8.	*Himalrandia tetrasperma*	Rubiaceae	0.57	9.43	-	-	-	-
9.	*Indigofera heteranthe*	Fabaceae	-	-	2.53	25.44	-	-
10.	*Prinsepia utilis*	Rosaceae	0.34	6.86	-	-	-	-
11.	*Rhus parviflora*	Anacardiaceae	2.63	26.23	-	-	-	-
12.	*Rosa brunonii*	Rosaceae	-	-	3.4	30.83	4.47	33.06
13.	*Rubus ellipticus*	Rosaceae	2.29	22.08	0.53	11.52	5.20	36.76
14.	*Sarcococa saligna*	Buxaceae	1.03	13.16	2.87	27.45	1.93	20.97
15.	*Skimmia anquitifolia*	Rutaceae	-	-	-	-	3.87	30.00
16.	*Smilax aspera*	Smilacaceae	-	-	2.4	24.62	-	-
17.	*Tertrastigma serrulatum*	Vitaceae	2.06	20.51	2.07	22.10	-	-
18.	*Thamnocalamus falconeri*	Poaceae	-	-	-	-	0.47	9.98
19.	*Urtica dioca*	Urticaceae	5.37	39.32	1.67	20.05	-	-
20.	*Viburnum cylindricum*	Caprifoliaceae	1.83	19.70	-	-	-	-
21.	*Viburnum nurvosum*	Caprifoliaceae	-	-	3.4	31.11	7.07	46.06

Table 2. Continued

S.N.	Species	Family	FT1		FT2		FT3	
			Density	IVI	Density	IVI	Density	IVI
	Herbs							
1.	*Achyranthes aspera*	Amaranthaceae	82.86	16.11	-	-	-	-
2.	*Agrimonia pilosa*	Rosaceae	-	-	-	-	56.67	13.58
3.	*Anaphalis tripilinervis*	Asteraceae	-	-	105	19.04	-	-
4.	*Arisaema conicinum*	Araceae	-	-	-	-	68.33	15.34
5.	*Artemisia roxburghiana*	Asteraceae	17.14	8.23	-	-	-	-
6.	*Aster penducularis*	Asteraceae	-	-	-	-	23.33	7.83
7.	*Bergenia ciliata*	Saxifragacea	40	10.03	-	-	-	-
8.	*Bidens pilosa*	Asteraceae	82.86	16.15	-	-	-	-
9.	*Bistorta amplexicaulis*	Polygonaceae	-	-	10	4.59	-	-
10.	*Boerhavia diffusa*	Nyctaginaceae	22.86	6.95	-	-	-	-
11.	*Calanthe plantaginea*	Orchidaceae	34.29	9.12	-	-	-	-
12.	*Carpesium nepalenese*	Asteraceae	5.71	3.32	-	-	-	-
13.	*Cirsium wallichii*	Asteraceae	62.86	13.72	-	-	-	-
14.	*Duchesnea indica*	Rosaceae	57.14	13.46	-	-	-	-
15.	*Erigeron multiradiatus*	Asteraceae	-	-	91.67	16.74	95	19.062
16.	*Euphorbia pilosa*	Euphorbiaceae	-	-	83.33	15.96	-	-
17.	*Fragaria nubicola*	Rosaceae	100	18.54	208.33	31.09	241.67	37.23
18.	*Galium asperifolium*	Rubiaceae	22.86	6.95	-	-	-	-
19.	*Gentiana pedicellata*	Gentianaceae	-	-	98.33	17.66	-	-
20.	*Geranium nepalensis*	Geraniaceae	8.57	4.55	-	-	23.33	9.13
21.	*Goodyera fusca*	Orchidaceae	-	-	48.33	11.00	-	-
22.	*Hedychium spicatum*	Zingiberaceae	-	-	6.67	4.82	33.33	9.66
23.	*Hemiphragma heterophyllum*	Scrophulariaceae	-	-	81.67	15.36	145.00	25.71
24.	*Impatiens sulcata*	Balsaminaceae	-	-	183.33	31.19	18.33	9.30
25.	*Micromaria biflora*	Lamiaceae	28.57	8.03	-	-	-	-
26.	*Ophiopogon intermidius*	Asparagaceae	-	-	10	6.98	-	-
27.	*Origanum vulgare*	Lamiaceae	42.86	10.33	30	8.41	-	-
28.	*Plantago depressa*	Plantaginaceae	-	-	-	-	46.67	11.95
29.	*Plantago himalaica*	Plantaginaceae	-	-	75	14.62	-	-
30.	*Plectranthus japonicus*	Lamiaceae	-	-	28.33	8.06	-	-
31.	*Potentilla fulgens*	Rosaceae	-	-	25	7.12	115	21.71
32.	*Primula denticulata*	Primulaceae	-	-	-	-	30	9.08
33.	*Prunella vulgaris*	Lamiaceae	-	-	60	12.60	-	-
34.	*Pteracanthes alatus*	Acanthaceae	-	-	-	-	165	29.88
35.	*Ranunaculus arvensis*	Ranunculaceae	154.29	24.70	-	-	-	-
36.	*Reinwardtia indica*	Liliaceae	162.86	25.75	-	-	-	-
37.	*Rubia manjith*	Rubiaceae	97.14	18.13	-	-	-	-
38.	*Rumex nepalensis*	Polygonaceae	88.57	17.14	61.67	12.83	-	-
39.	*Senecio nudicaulis*	Asteraceae	82.86	17.48	-	-	40	10.86
40.	*Sonchus brachyotus*	Asteraceae	-	-	50	11.27	55	13.33
41.	*Stellaria semivestita*	Caryophyllaceae	-	-	8.33	5.90	-	-
42.	*Swertia paniculata*	Gentianaceae	25.71	7.49	-	-	-	-
43.	*Taraxacum officinale*	Asteraceae	-	-	70	13.88	43.33	11.45
44.	*Thalictrum foliolosum*	Ranunculaceae	97.14	19.00	10	6.98	71.67	15.78
45.	*Trifolium rapens*	Fabaceae	-	-	28.33	8.06	15	6.43
46.	*Valeriana jatamansii*	Valerianaceae	77.14	15.24	-	-	-	-
47.	*Viola pilosa*	Violaceae	31.43	9.59	85	15.82	121.67	22.68

FT1, forest type 1; FT2, forest type 2; FT3, forest type 3.

high species richness (Rawal et al. 2012).

A total of 21 shrub species were observed in all the three Oak forest types, amongst which *Eupatorium adenophorum* (1,063 ind ha^{-1}) was dominant in *Q. leucotrichophora* forest, while *Berberis aristata* was dominant in *Q. floribunda* (400 ind ha^{-1}) and *Q. semecarpifolia* (787 ind ha^{-1}) forest types. The overall shrub density in Oak forest types ranged between 3,000 to 3,867 shrubs ha^{-1}. Gairola et al. (2012) reported 3,100 shrubs ha^{-1} in *Q. semecarpifolia* forest from Garhwal Himalaya. The lowest total herb density (140,833 herbs ha^{-1}) was recorded in FT3. *Reinwardtia indica* (16,286 ind ha^{-1}) was the dominant herb, followed by *Ranunaculus arvensis* (15,428 ind ha^{-1}) and *Fragaria nubicola* (10,000 ind ha^{-1}) in *Q. leucotrichophora* forest, *Fragaria nubicola* was dominant in *Q. floribunda* forest (20,833 ind ha^{-1}), followed by *Impatiens sulcata* (18,333 ind ha^{-1}), whereas *Fragaria nubicola* (24,167 ind ha^{-1}) and *Pteracanthes alatus* (16,500 ind ha^{-1}) were the dominant herbs in *Q. semecarpifolia* forest (Table 2).

Plant diversity

The understanding of forest structure and composition is a prerequisite to describe various ecological processes and also to model the functioning and dynamics of forests (Elourard et al. 1997). The nature of forest communities largely depends on the ecological characteristics of sites, species diversity and regeneration status of tree species. The species richness and diversity of trees are fundamental to total forest biodiversity, because trees provide resources and habitat for almost all the species. Species richness is a simple and easily interpretable indicator of biological diversity. Diversity is usually considered as a function of the relative distribution of individuals among species, which is regulated by long-term factors such as important forest covers in Himalayan region as they provide sustainable goods and services to village communities and sustain rich biodiversity.

In this study the higher Shannon diversity index value (0.62) was recorded for *Q. semecarpifolia* (FT3) forest, whereas lower (0.55) for *Q. floribunda* (FT2) forest. The recorded diversity index values were lesser to the earlier reported values i.e., 2.66 for *Q. leucotrichophora*; 2.53 for *Q. floribunda* and 1.41 for *Q. semecarpifolia* forests (Singh and Rawat 2012), 1.2 to 2.7 for *Q. floribunda* forest (Kumar and Ram 2005), 0.76 to 1.50 for *Q. floribunda* forest (Lodhiyal et al. 2013). However, Gairola et al. (2011) have reported the diversity index values as; 0.46 for *Q. semecarpifolia* forest and 0.49 for *Q. floribunda* forest, which were closer to our values. The herb diversity was more than trees and shrubs in all the Oak forests (Table 1). The evenness in tree layer was found highest (0.28) for *Q. leucotrichophora* forest (Table 1).

In shrub layer highest value (1.07) of species diversity was recorded in FT2 and lowest (0.96) in FT3 whereas, the highest value of Simpson's Index (0.12) was achieved for FT3 and lowest 0.09 for FT2. Malik and Bhatt (2015) also reported higher shrub diversity (3.53-3.34) at mid altitudes (between 2,250-2,600 m asl) for mixed Oak forests. High species richness with generally overlapping niches may be due to higher diversity which always oozes higher stability (Kharkwal 2009). Higher diversity in shrub layer in FT2 and FT1 may be a consequence of moderate disturbance which gave birth to a variety of micro-site. In herb layer highest species diversity (1.32) was recorded in FT1 and lowest (1.23) in FT3 which clearly indicated that the high mountain ridge top forests of *Q. semecarpifolia* (occurring between 2,418-3,540 m asl) were unable to support the

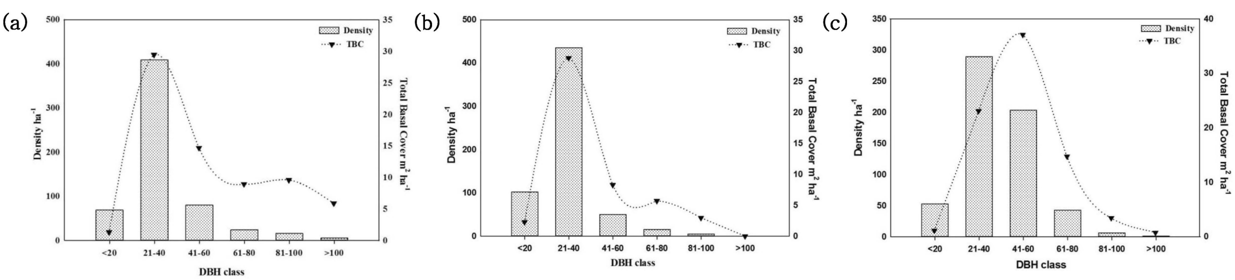

Fig. 2. (a) DBH class based distribution of density (trees ha^{-1}) and TBC (m^2 ha^{-1}) in *Q. leucotrichophora* forest. (b) DBH class based distribution of density (trees ha^{-1}) and TBC (m^2 ha^{-1}) in *Q. floribunda* forest. (c) DBH class based distribution of density (trees ha^{-1}) and TBC (m^2 ha^{-1}) in *Q. semecarpifolia* forest.

herbs as well as shrubs growth. Restricted shrub growth (lower diversity) in FT3 at higher altitudes may also be due to harsh climatic conditions. The Similarity Index value was highest (53.05%) with least value of β-diversity (1.05) for the shrub layer, however, minimum value of Similarity Index (27.73%) was recorded for sapling layer, where the highest β-diversity (2.63) persisted, which has revealed that the species were more similar in shrub strata than in other studied vegetation layers (Table 1).

Population structure and regeneration status

In all the oak forest types, maximum number of in-

Table 3. Component-wise biomass (t ha^{-1}) of tree layer in oak dominated ridge forests of high mountain of Garhwal Himalaya

Species	Bole	Bole bark	Branch	Twig	Foliage	Stump roots	lateral roots	Fine roots	Total
Banj oak forest (FT1)									
Alnus nepalensis	1.46	0	0.91	0.37	0.21	0.47	0.05	0.004	3.47
Betula alnoides	1.75	0	1.08	0.43	0.25	0.55	0.06	0.005	4.12
Lyonia ovalifolia	1.74	0.13	1.21	0.65	0.19	0.78	0.07	0.04	4.80
Pinus roxburghii	0.91	0.03	0.35	0.31	0.07	0.33	0.14	0.02	2.16
Pyrus pashia	0.68	0	0.44	0.20	0.12	0.27	0.03	0.003	1.73
Quercus floribunda	38.52	2.12	10.66	1.80	1.80	5.27	2.66	0.82	63.65
Quercus leucotrichophora	162.20	0	96.99	30.14	14.09	78.70	13.74	1.18	397.04
Rhododendron arboreum	8.90	0.27	3.30	2.95	0.68	2.85	1.25	0.15	20.34
Total	216.15	2.54	114.93	36.84	17.42	89.22	18.00	2.23	497.32
Moru oak forest (FT2)									
Abies pindrow	4.22	0.57	0.89	0.39	0.20	0.82	0.44	0.18	7.73
Betula alnoides	0.24	0	0.15	0.06	0.03	0.07	0.01	0.00	0.56
Cedrus deodara	2.54	0	1.47	0.49	0.29	0.60	0.07	0.00	5.45
Cupressus torulosa	0.09	0	0.06	0.03	0.02	0.04	0.004	0.0004	0.22
Ilex dipyrena	0.60	0.03	0.26	0.04	0.02	0.002	0.08	0.04	1.07
Lyonia ovalifolia	0.79	0.06	0.55	0.30	0.08	0.35	0.03	0.02	2.19
Neolitsea cuipala	0.18	0.01	0.06	0.01	0.01	0.07	0.05	1.02	1.41
Neolitsea pallens	0.25	0.01	0.08	0.02	0.01	0.09	0.07	1.41	1.94
Quercus floribunda	312.55	17.55	89.04	16.14	15.96	46.96	24.09	7.48	529.76
Quercus leucotrichophora	1.73	0	1.05	0.34	0.16	0.89	0.16	0.01	4.34
Rhododendron arboreum	8.94	0.26	3.53	3.08	0.74	3.41	1.42	0.19	21.58
Symplocos paniculata	0.22	0.01	0.08	0.03	0.01	0.08	0.01	0.01	0.45
Total	332.35	18.50	97.21	20.93	17.54	53.39	26.43	10.36	576.71
Kharsu oak forest (FT3)									
Abies pindrow	18.61	2.44	3.92	1.69	0.84	3.69	1.94	0.74	33.87
Abies spectabilis	13.65	1.84	2.88	1.29	0.67	2.66	1.43	0.62	25.03
Acer acuminatum	0.37	0.02	0.11	0.04	0.01	0.11	0.03	0.01	0.69
Betula utilis	3.59	0	2.14	0.76	0.45	0.95	0.10	0.01	8.01
Ilex dipyrena	0.87	0.05	0.37	0.05	0.03	0.003	0.12	0.05	1.55
Lyonia ovalifolia	0.08	0.01	0.06	0.03	0.01	0.04	0.003	0.002	0.23
Picea smithiana	3.59	0	2.11	0.72	0.42	0.88	0.10	0.01	7.82
Pinus wallichiana	0.97	0.03	0.36	0.32	0.08	0.31	0.14	0.02	2.23
Quercus floribunda	1.71	0.10	0.51	0.11	0.10	0.30	0.16	0.05	3.03
Quercus semecarpifolia	304.52	26.76	79.16	12.09	9.77	78.63	34.40	13.04	558.36
Rhododendron arboreum	5.37	0.16	2.11	1.85	0.44	2.02	0.85	0.11	12.91
Sorbus cuspidata	1.88	0	1.10	0.38	0.22	0.46	0.05	0.003	4.10
Symplocos paniculata	0.12	0.01	0.04	0.02	0.01	0.04	0.004	0.004	0.24
Taxus wallichiana	2.38	0	1.38	0.45	0.27	0.55	0.06	0.003	5.10
Total	357.71	31.41	96.26	19.78	13.31	90.65	39.39	14.66	663.16

dividuals were recorded in 21-40 cm dbh class i.e., in FT1 (67.8%); FT2 (71.7%) and FT3 (48.7%), followed by 13.3% and 34.2% in dbh class 41-60 cm in FT1 and FT3 respectively, whereas in FT2, 16.8% individuals were observed in ＜20 cm dbh class, which may be considered as immature regenerating forest (Fig. 2). Dimri et al. (2014) also reported higher altitudinal *Q. semecarpifolia* forests as old growth forests (Individuals found above 100cm dbh class), and *Q. leucotrichophora* and *Q. floribunda* forests as young regenerating forests (higher number of individuals in lower dbh classes).

In *Quercus leucotrichophora* forest (FT1) most of the tree species (40%) exhibited good regeneration, followed by poor regeneration and new recruitment (20%) and fair and not regenerating (10%) (Fig. 3). *Q. leucotrichophora*, *L. ovalifolia*, *R. arboreum* and *P. pashia* indicated good regeneration on the ridge tops situated between 1,428-2,578 m asl. In FT1 *Ilex dipyrena* and *Neolitsea cuipala* were represented by seedlings only and therefore observed to be new on lower altitudinal ridge tops. *Betula alnoides* (9 ind ha^{-1}) on the other hand was represented in tree stage only in FT1 as well as in FT2 and its seedlings and saplings were absent completely, which means it was not reproducing. Benton and Werner (1976) suggested that such type of population could become extinct if the tendency continues. *Alnus nepalensis* and *Pinus roxburghii* showed poor regeneration due to weak adaptation on ridge tops of FT1.

In *Quercus floribunda* forest (FT2), 54% of the tree species indicated good regeneration, 15% as poor and 8% were not regenerating. *Lindera pulcherrima* (7 ind ha^{-1}) was the only new recruitment in this forest type between the altitudes 2,430-2,697 m asl. Therefore compositional changes are expected in this forest type in near future.

In *Quercus semecarpifolia* (FT3), 40% tree species showed good regeneration, whereas *Acer acuminatum*, *Lyonia ovalifolia*, *Quercus floribunda*, *Sorbus cuspidata* and *Taxus wallichiana* together constituted the not regenerating category, including 33% tree species (which is highest amongst all the three forest types). This is a cause of concern because climatic conditions were not suitable for these species on high mountain ridges and therefore they were not reproducing (their population may become extinct in near future). *Prunus cornuta* was the new recruitment in high altitudinal Oak forests, because it was observed in seedling and sapling stages only (it may establish itself in *Q. semecarpifolia* forest in due course of time to become canopy or sub-canopy species). It was clear from the regeneration pattern of studied ridge Oak forests that only mid altitudinal transects exhibited good regeneration potential and subsequently it decreased with increasing altitudes.

Biomass and carbon storage

The quantification of biomass in forest ecosystems is a primary inventory data required for efficient forest manage-

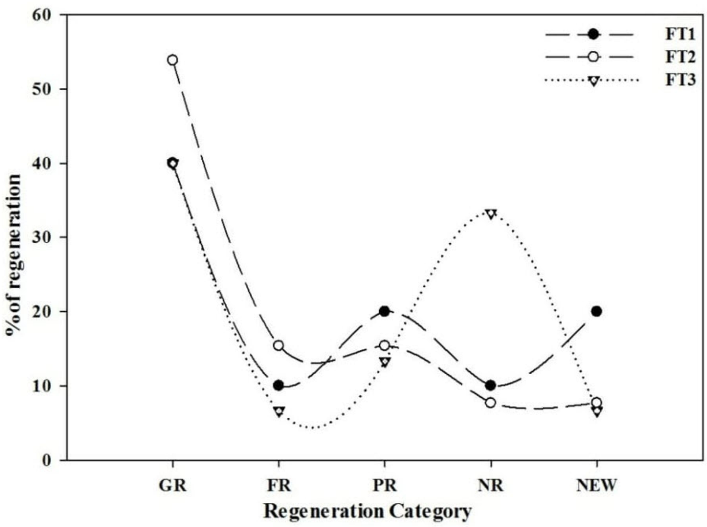

Fig. 3. Graphical representation of regeneration percentage in different Oak forest.

ment (Hall et al. 2006) to understand carbon pool changes and productivity of forests. Biomass assessment is also necessary because forest is affected by various factors such as deforestation, fire, harvesting, pests, silviculture and climate change (Schroeder et al. 1997), which cause changes in the forest ecosystem. Stem wood proved to be the most massive component among trees than stem bark, coarse root, branches and foliage. Biomass is a function of diameter at breast height (DBH), height (ht) and wood density in a given location. However, the contribution of these variables to the above ground biomass (AGB) differs from site to site, succession stage of the forest, distribution level, species composition etc. (Whitmore 1984). Live tree biomass estimates are essential for carbon accounting, bio-energy feasibility studies and other analyses.

The biomass production in all the *Quercus* forests oscillated from 497.32±83.70 t ha^{-1} (*Q. leucotrichophora* forest) to 663.16±93.85 t ha^{-1} (*Q. semecarpifolia* forest). The above-ground biomass contributed 78% to 84% of the total tree biomass in these forests. Our values are best fitted with the previously reported values for biomass production i.e., 387.3 Mg ha^{-1} for *Q. leucotrichophora* forest at 1,950 m asl by Rawat and Singh (1988); 782 Mg ha^{-1} for *Q. floribunda* forest at 2,200 m asl by Rana et al. (1989); and 590.2 Mg ha^{-1} for *Q. semecarpifolia* forest at 2,650 m asl by Adhikari et al. (1995). On the other hand somewhat lesser values i.e., 215.5 Mg ha^{-1} for mixed *Q. leucotrichophora* forest at 1,500-1,650 m asl; 429.7 Mg ha^{-1} for mainly *Q. floribunda* forest at 2,550-2,650 m asl; and 389.5 Mg ha^{-1} for mainly *Q. semecarpifolia* forest at 2,650-2,850 m asl were also reported by Gairola et al. (2011) for Oak mixed forests. However, the biomass production of 272.5 Mg ha^{-1} for *Q. leucotrichophora* forest; 511.2 Mg ha^{-1} for *Q. floribunda* forest, and 507.8 Mg ha^{-1} for *Q. semecarpifolia* forest was observed by Dimri et al. (2016). Singh et al. (1994) have reported a high range of biomass (500-600 Mg ha^{-1}) in Oak forests from Kumaun Himalaya. The bole biomass contributed maximum in *Q. leucotrichophora* forest (43.46%) and *Q. semecarpifolia* forest (57.63%). The maximum branch biomass (23.11%) was recorded in FT1 whereas, minimum (14.51%) in FT3. Fine roots contributed the minimum (0.45 to 2.21%) of total biomass in all the forest types (Table 3). In FT1, the *Q. leucotrichophora* contributed maximum (79.84%) to the total forest biomass, followed by *Q. floribunda* (12.80%) and *R. arboreum* (4.09%).

Percent contribution of bole, branches, twigs and foliage of *Q. leucotrichophora* to the total forest AGBD was 41.82%, 25.01%, 7.77% and 3.65% respectively and the total AGBD of *Q. leucotrichophora* was 61.01% of the total forest biomass density. In FT2 bole, bole bark, branches, twigs and foliage of *Q. floribunda* contributed 64.24%, 3.61%, 18.30%, 3.32% and 9.65% to the total AGBD respectively, however 78.24% was contributed by AGBD of *Q. floribunda* to the total forest biomass density. In FT3, bole, bole bark, branches, twigs and foliage of *Q. semecarpifolia* accounted 58.74%, 5.16%, 15.27%, 2.33% and 1.88% respectively to the total AGBD of the forest. The AGBD of *Q. semecarpifolia* contributed 65.19% to total forest biomass density (Table 3).

The bole biomass of *Q. leucotrichophora* contributed 41.82% to the total above ground biomass of all the species in FT1. The recorded values were best fitted with the reported values of bole biomass (36.6 to 60.7% by Negi et al. 1983). In FT2 the *Q. floribunda* contributed significantly (91.86%) to the total forest biomass, followed by *R. arboreum* (3.74%). The percent contribution of bole and branch biomass of *Q. floribunda* to the total above ground biomass density was 64.24% and 18.30% respectively (Table 3). Negi et al. (1983) reported 34.2% to 60.2% contribution of bole and 21.3% to 35.6% of branch biomass for the temperate forest of Kumaun Himalaya. In FT3 the contribution of *Q. semecarpifolia* to the total biomass density was 84.20%. The percent contribution of bole biomass of *Q. semecarpifolia* to the total forest biomass was 58.74% (Table 3). Thus the biomass production of different components im each forest type followed the following order:

FT1: Bole > branch > stump roots > twig > lateral roots > foliage > bole bark > fine roots.

FT2: Bole > branch > stump roots > lateral roots > twig > bole bark > foliage > fine roots and

FT3: Bole > branch > stump roots > lateral roots > bole bark > twig > fine roots > foliage.

In this study we have observed that the composition of conifers species increased with increasing altitude. Therefore, in the higher altitudinal *Q. semecarpifolia* forests more coniferous species (05) were encountered, which had lesser twig/ crown expanse. The *Q. floribunda* forests had three coniferous species whereas in *Q. leucotrichophora* forest only one coniferous species (i.e., *Pinus roxburghii*) was present. Henceforth, the broadleaved species had comparatively more/longer twigs and *Q. leucotrichophora* (a broad crown oak species) contributed 81.81 percent to the total twig biomass in this forest. That is why twig biomass in FT1 was comparatively more than other oak forests.

The contribution of foliage to total above ground biomass was 2.6% to 4.5%. The total root biomass (below ground biomass density) in these forests ranged from 90.2 to 144.7 t ha^{-1}. Root biomass has contributed 15.6% to

Table 4. Carbon stock (C t ha^{-1}) of different components of tree species in some oak dominated forests

Species	Bole	Bole bark	Branch	Twig	Foliage	Stump root	Lateral roots	Fine roots	Total
Banj oak Forest (FT1)									
Alnus nepalensis	0.67	0	0.42	0.17	0.10	0.22	0.02	0.002	1.60
Betula alnoides	0.80	0	0.50	0.20	0.12	0.25	0.03	0.002	1.90
Lyonia ovalifolia	0.80	0.06	0.55	0.30	0.09	0.36	0.03	0.02	2.21
Pinus roxburghii	0.41	0.01	0.16	0.14	0.03	0.15	0.06	0.01	0.97
Pyrus pashia	0.31	0	0.20	0.09	0.05	0.12	0.01	0.001	0.80
Quercus floribunda	17.72	0.97	4.90	0.83	0.83	2.43	1.23	0.38	29.28
Quercus leucotrichophora	74.61	0	44.62	13.86	6.48	36.20	6.32	0.54	182.64
Rhododendron arboreum	4.10	0.12	1.52	1.36	0.31	1.31	0.57	0.07	9.35
Total	99.42	1.17	52.86	16.94	8.01	41.04	8.28	1.02	228.75
Moru Oak Forest (FT2)									
Abies pindrow	1.90	0.25	0.40	0.18	0.09	0.37	0.20	0.08	3.48
Betula alnoides	0.11	0	0.07	0.03	0.02	0.03	0.004	0.0002	0.26
Cedrus deodara	1.14	0	0.66	0.22	0.13	0.27	0.03	0.002	2.45
Cupressus torulosa	0.04	0	0.03	0.01	0.01	0.02	0.002	0.0002	0.10
Ilex dipyrena	0.28	0.02	0.12	0.02	0.01	0.001	0.04	0.02	0.49
Lyonia ovalifolia	0.37	0.03	0.25	0.14	0.04	0.16	0.01	0.01	1.01
Neolitsea cuipala	0.08	0.004	0.03	0.01	0.004	0.03	0.02	0.47	0.65
Neolitsea pallens	0.11	0.01	0.04	0.01	0.01	0.04	0.03	0.65	0.89
Quercus floribunda	143.77	8.07	40.96	7.42	7.34	21.60	11.08	3.44	243.69
Quercus leucotrichophora	0.80	0	0.48	0.16	0.07	0.41	0.07	0.01	2.00
Rhododendron arboreum	4.11	0.12	1.63	1.42	0.34	1.57	0.65	0.09	9.93
Symplocos paniculata	0.10	0.01	0.04	0.02	0.01	0.03	0.004	0.004	0.21
Total	152.81	8.51	44.69	9.62	8.06	24.54	12.15	4.76	265.15
Kharsu Oak Forest (FT3)									
Abies pindrow	8.38	1.10	1.76	0.76	0.38	1.66	0.87	0.33	15.24
Abies spectabilis	6.14	0.83	1.30	0.58	0.30	1.20	0.64	0.28	11.26
Acer acuminatum	0.17	0.01	0.05	0.02	0.01	0.05	0.01	0.004	0.32
Betula utilis	1.65	0	0.99	0.35	0.21	0.44	0.05	0.003	3.68
Ilex dipyrena	0.40	0.02	0.17	0.02	0.01	0.001	0.06	0.02	0.71
Lyonia ovalifolia	0.04	0.003	0.03	0.01	0.004	0.02	0.002	0.001	0.11
Picea smithiana	1.61	0	0.95	0.32	0.19	0.40	0.04	0.003	3.52
Pinus wallichiana	0.44	0.01	0.16	0.15	0.03	0.14	0.06	0.01	1.00
Quercus floribunda	0.79	0.05	0.23	0.05	0.05	0.14	0.07	0.02	1.40
Quercus semecarpifolia	140.08	12.31	36.41	5.56	4.49	36.17	15.82	6.00	256.85
Rhododendron arboreum	2.47	0.07	0.97	0.85	0.20	0.93	0.39	0.05	5.94
Sorbus cuspidata	0.87	0	0.51	0.17	0.10	0.21	0.02	0.001	1.89
Symplocos paniculata	0.05	0.003	0.02	0.01	0.003	0.02	0.002	0.002	0.11
Taxus wallichiana	1.07	0	0.62	0.20	0.12	0.25	0.03	0.002	2.30
Total	164.15	14.40	44.17	9.06	6.10	41.62	18.08	6.73	304.31

22.01% to the total forest biomass. These values are higher to the values (47.6 to 95.9 t ha^{-1}) reported for Oak forest by Rawat and Singh (1988), which may be because we have selected only the mature, old growth forests in the present study to calculate the maximum production potential of these forests for conservation of biomass and carbon. The total carbon density (TCD) in these Oak forests ranged from 228.75±22.27 t C ha^{-1} (*Q. leucotrichophora*) to 304.31±18.12 t C ha^{-1} (*Q. semecarpifolia*) (Table 4). Rana et al. (1989) reported the higher range of carbon stocks values (440.1 t ha^{-1}) for *Quercus floribunda* dominated mixed oak forests from Garhwal Himalaya. Sharma et al. (2011) had reported the TCD values for *Q. leucotrichophora* (77.3-102.8 t ha^{-1}), *Q. floribunda* (87.8-193.7 t ha^{-1}) and *Q. semecarpifolia* (107.2-160.1 t ha^{-1}) forests, Similarly Dimri et al. (2016) have recorded the TCD values 122.6 t C ha^{-1} for *Q. leucotrichophora*, 230 t C ha^{-1} for *Q. floribunda*, 228.5 t C ha^{-1} for *Q. semecarpifolia* forests, which are lesser to the values reported for these forests in this study. The statistical results showed significant difference ($F=5.990$, $p=0.007$) between overall TBD and TCD values in different oak forests studied. We observed that carbon density increased among the oak dominated forests with increasing altitude, which suggested that the high altitude mountain ridge top oak forests are more suitable for sequestering the carbon. Several authors have supported this view that biomass production and carbon assimilation increased with increasing altitude (Gairola et al. 2011; Dimri et al. 2016; Sharma et al. 2016). Our study also justified that biomass and carbon densities increased with stand age and altitude and varied greatly across biomes, especially in temperate forests (Pregitzer and Euskirchen 2004).

The forest ecosystems fix more carbon and possess more carbon density than croplands or grasslands (Zhou et al. 2011). Approximately 80% of the aboveground carbon is found in the form of standing timber, branches and foliage and 40% of the world's belowground carbon stock is sustained in roots in forest ecosystem (IPCC 2001; Dixon et al. 1994). The total carbon pool in forest ecosystems was estimated to be about 1,150 Gt, of which 49% is in the boreal forests, 14% in temperate forests and 37% in tropical forests (Dixon et al. 1994). Pan et al. (2011) have reported that geographically, 471 T 93 PgC (55%) is stored in tropical forests, 272 T 23 PgC (32%) in boreal forests and 119 T 6 PgC (14%) in temperate forests. Higher TBC at higher altitudes in Oak forests seems to yield high productivity; hence Oaks are important forest types to sequester carbon globally.

Conclusion

The co-dominant tree species varied widely in all the oak forest types. Most of the species showed uniform distribution pattern. Species like *Ilex dipryena, Neolitsea cuipala* (FT1), *Prunus cornuta* (FT3) and *Lindera pulcherrima* (FT2) were represented in seedling stage only which means they are the new introduction (recent invaders) in their respective forest types. Due to infrequent reproduction and declining populations of some of the native species like *Betula alnoides* (FT1), *Acer acuminatum, Taxus wallichiana, Sorbus cuspidata*, and *Symplocos paniculata* (FT3) compositional changes are expected in near future. Due to climate change the ridge top vegetation is expected to face drastic composition changes at all altitudes. Although conifer forests were observed to be more efficient in sequestrating carbon and several authors have suggested for conservation of *A. spectabilis, A. pindrow, C. deodara* as prized species but contribution of broadleaf forests (generally Oak forests) to store carbon and thrive at harsh climatic conditions cannot be ignored. Amongst the oak forests maximum biomass production (663.16±93.85 t ha^{-1}) and carbon storage potential (304.31±18.12 t C ha^{-1}) were recorded for *Quercus semecarpifolia* forest (FT3), whereas minimum (497.32 t ha^{-1} and 228.75±22.7 t C ha^{-1} respectively) for *Quercus leucotrichophora* forest (FT1). This may be because of the location of Banj Oak forests closer to habitation zone. The carbon assimilation in various oak forests was observed to increase with an increase in altitude.

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